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on Pulsations and Rapid Variations
in Geomagnetism and Earth Currents

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Terrestrial Magnetism [illegible]

Atmospheric [illegible]

The Ionosphere [illegible]

Radio Wave [illegible]

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JOURNAL OF GEOMAGNETISM AND GEOELECTRICITY

The fields of interest of this quarterly Journal are as follows:

Terrestrial Magnetism	Aurora and Night Airglow
Atmospheric Electricity	The Ozone Layer
The Ionosphere	Physical States of the Upper Atmosphere
Radio Wave Propagation	Solar Phenomena relating to the Above Subjects
Cosmic Rays	Electricity within the Earth

The text should be written in English, German or French. The price is set as 1 dollar per number.

The Editors

1. Ionizations in the Outer Atmosphere Infered from Whistling Atmospherics

By J. Outsu and A. Iwai

The Research Institute of Atmospherics, Nagoya University

Abstract

Some dispersions of whistling atmospherics ionization densities in the outer atmosphere are roughly estimated. And diurnal variations of electron density are obtained in lower parts of outer atmosphere. In order to examine the origin of the ionization kp index is compared with rate occurrence of whistlers, but no correlation is obtained, though the correlation is altered slightly positive when value of kp is taken two days in advance. And observations at low latitudes show that an ionised hydrogen atomosphere is likely in the exosphere.

§ 1. Introduction

Since Storey's original work (1953) on whistling atmospherics, systematic observations have been carried out at various latitudes in the world. For results of these observations all support his theory and have brought not a less progress in the field of V.L.F. phenomena. Accordingly, the properties of the outer atmosphere, investigated from these phenomena, have become clear step by step. Especially, the nose-whistlers made it possible to seperate the effect of electron gyro-frequecy and plasma frequency on their dispersions, and thus informations about intensities of the earth's magnetic field and electron densities at distances of four to five earth's radii from the surface of the earth, are expected to become more reliable. But at present, available data of nose-whistler have not been reported. Several problems about the exact knowlege of propagation paths yet remain owing to possible multiple paths, complex excitation process and deviation of propagation from the magnetic-field direction (Maeda and Kimura, 1956). This makes quantitative estimations of physical properties of the outer atmosphere somewhat inaccurate. For instance, at middle latitudes sources of long whistlers have been found within 2,000 km from locations of observatories.

At this stage of study, we survey what have been obtained about the ionization of the outer atmosphere, but a stress is put on lower spaces, because our observation have been limited within lower latitudes and available data from higher latitudes have not been yet obtained.

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Electron densities of the outer atmosphere can be estimated from the characteristics of dispersion of whistler. (In the following, all quantitative results of electron density

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Electron densities of the outer atmosphere can be estimated from the characteristics of dispersion of whistler, (in the following, all quantitative results of electron density

are obtained under assumptions that whistlers propagate quite along lines of geomagnetic force generated by a magnetic dipole at the center of the earth). A typical value for the dispersion of short whistlers observed at a middle latitude, for instance, Cambrige, (geomag. lat. 55°), was about 60 $sec^{1/2}$. The contribution of the regular ionospheric layers to the dispersion is only about 3 $sec^{1/2}$. Then the remainning dispersion must be produced in the outer atmosphere, hence the mean electron density required is about 2,300 cm^{-3}. Thus, the electron density at a height of about 2 earth radii is known to amount to an order of few thousand cm^{-3}. Observations at higher latitudes, for instance, College (geomag. lat 65°), indicate that the ionization continues up to heights of 4 or 5 earth radii, and short nose-whistlers (Helliwell & others, 1956) consisted of multiple traces originating from a single source, suggest that the ionization decreases with the distance from the earth at such heights. and the electron density calculated from an uniform ionization model is about 775 cm^{-3} (corresponding to plasma frequence 250 kc).

Here, we will examine lower parts of the outer atmosphere in detail. As seen in Fig. 1, diurnal variations of dispersion of whistlers observed at Toyokawa (TO) and

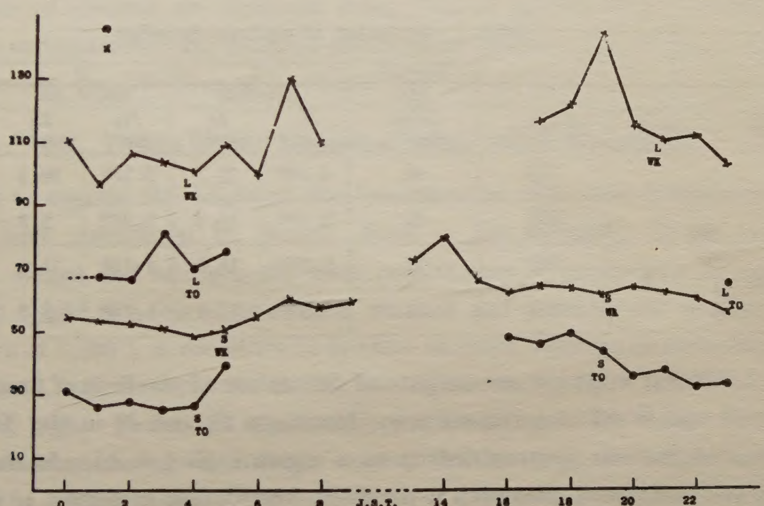

Fig. 1. Diurnal variation of whistler dispersion July 13, 1937—December 31, 1957.
● Toyokawa, S: Short whistler
× Wakkanai, L: Long whistler

Wakkanai (WK) had a regular tendency, that dispersions decreased gradually with the lapse of time from the evening till near sunrise, after then they began to rise. (Irregularities on the curves for long whistlers may due to scarcity of data). This tendency of variation of dispersions is similar to that of electron density in the regular ionosphere. In fact, a linear relation was obtained between dispersions observed at Toyokawa and f_0F_2 observed in Japan, (Fig. 2). From fhis behaviour of dispersion, diurnal variations of electron density in the lower part of the outer atmosphere were calculated. In this calculation, the space in which whistlers propagate is divided into three regions according to height. Region 1 is between 100 and 500 km above the ground; region 2 is between 500 and 1,320 km, and region 3 is between 1,320 and 3,200 km,

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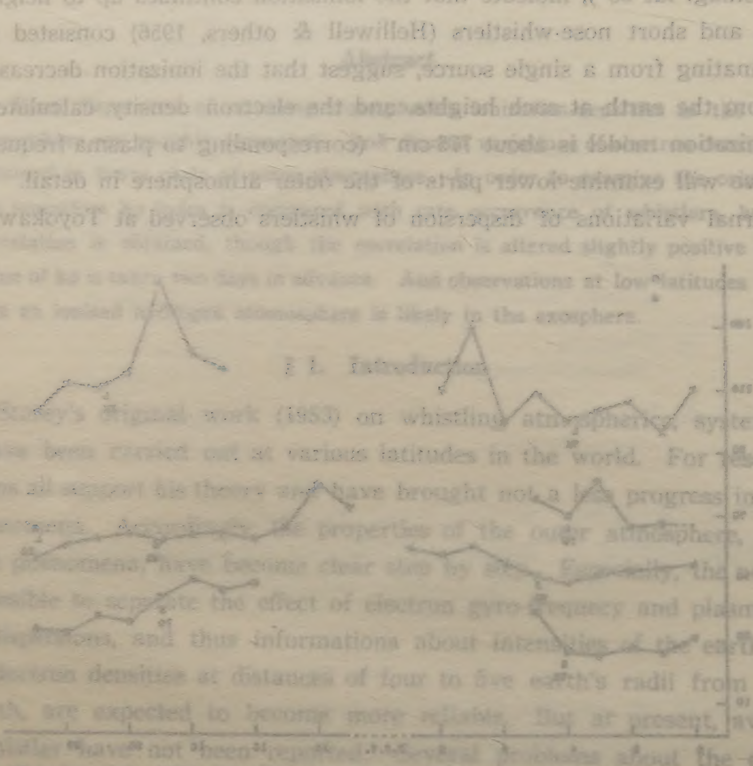

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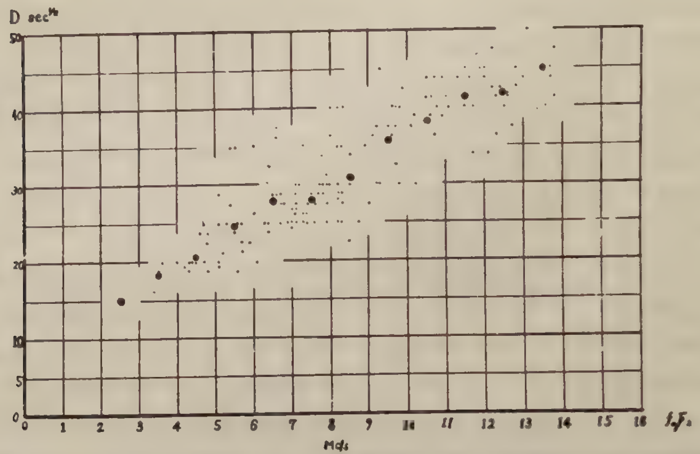

Fig. 2. Relation between f_0F_2 observed at Kokubunji and Yamagawa and dispersions of short whistlers observed at Toyokawa, Dec. 1955——Feb. 1957.

Table 1. Variation of electron densities

			Region km	1 100–500		2 500–1,320		3 1,320–3,200	
Time J.S.T.	f_0F_2 Mc/s	Observa.	Disp. Sec$^{1/2}$	N_1 cm^{-3}	D_1 sec$^{1/2}$	N_2 cm^{-3}	D_2 sec$^{1/2}$	N_3 cm^{-3}	D_3 sec$^{1/2}$
18.00	10.3	TO	48	$9.7\,10^{5}$	21.7	$5.3\,10^{4}$	26.3		
		WK	64	$9.7\,10^{5}$	15.2	$5.3\,10^{4}$	9.2	$2.4\,10^{4}$	39.6
00.00	7.6	TO	31	$5.3\,10^{5}$	16.0	$1.7\,10^{4}$	15.0		
		WK	54	$5.3\,10^{5}$	11.2	$1.7\,10^{4}$	5.2	$2.1\,10^{4}$	37.6

where 1,320 and 3,200 km are heights of the apices of the lines of force going through Toyokawa and Wakkanai, respectively. Notations D_i and N_i in the Table 1 are dispersions and uniform electron density in a region i, (i=1,2,3,). As the value of N_1 an average one is adopted, assuming a parabolic distribution in region 1, whose height of maximum density is taken to be 400 km above the ground. This is rather higher than in the actual F_2 layer. But in order to know the general property of variation of density this may be admittable. The results are given in Table 1, which show that, generally, the density decreases as height increases, except the case of region 2 at midnight, which may be due to an excessive value of N_1 and that the density is reduced considerablly in heights between 500 and 1,320 km as well as at normal ionosphere as time elapses from 1800 to 0000, but the decrement is small in heights between 1,320 and 3,200 km. Further, the diurnal variation of electron density may become smaller as altitude rises, for results obtained at higher latitudes have indicated little variation of dispersion with time of day, although this may be partially due to possible multiple paths in observations at higher latitudes, which cause a considerablly wide variation of dispersion of whistlers observed at a particular station, and make a systematic examination of dispersion variation difficult.

Thus, the outer atmosphere is known to be ionized from the lowest part to the height of several earth radii. And the electron density diminishes from a value of several hundred thousand to several hundred per cm^3 as altitude rises from thousand to thirty thousand km above the earth. And in its lower part the density exhibites a clear diurnal variation, which is very analogous to the variation of electron density in the regular ionospheric layers.

Whistlers of pure tone type suggest that they have travelled through a regularly ionized medium and have not met discontinuous regions, their dimension being comparable with wave lengths of the whistler. Being sometimes slightly spread in the deep of night, whistlers observed at Toyokawa are generally pure, but at Wakkanai they are frequently spread, so it may be presumed that the ionization distribution is usually regular within a certain height between 1,300 and 3,200 km. But in very magneticaly disturbed periods whistlers observed at Toyokawa were spread, so magnetic activites might cause disturbances in the ionization distribution. At higher latitudes most of the whistlers are swish type composed of multi-component, that suggests the concentrations of electron are produced along lines of earth's magnetic field. Generations of this concentration are perhaps due to effect of solar streams, for in magneticaly disturbed periods, the whistlers at Toykawa also reveal swish and pair types.

§ 3. Origin of the Ionization in the Outer Atmosphere

In order to explain the origin of the ionization in the outer atmosphere, several cases have been considered by Storey. First is the ionization of an atmosphere, consisted of oxigen and nitrogen the main constituents of ionospheric F_2 layer, which extends up to height of a few earth radii in thermal and gravitational equilibrium. But a temperature of 7,200°k is necessary to produce so much densities as estimated in space about few earth radii distant from the surface of the earth, which is believed to be geophysically too high. Next is the upper reaches of ionization in the regular ionosphere by turbulence produced during ionospheric storms. In this case, the ionization density of F_2 layer will be reduced, consquently increments of dispersion are expected to correspond to reductions of f_0F_2. But in examinations, reversed relations were obtained. Other explanation is a production of ionization by charged particles ejected from the sun during solar active periods. In this case, a positive correlation will be expected between rate occurrences of whistlers and magnetic disturbance. We examined this expected correlation statistically using whistler data obtained from a two-minute observation duration beginning at 35 minute every hour, at six observatories, two of which lie in Japan and the others in Australia. Their locations and observation periods are tabulated in Table 2. As these observatories are distributed in both hemispheres, seasonal effects on occurrence of whistlers are advantegeously eliminated. Though days of no observation happened occasionally at each observatory are ignored, this will not affect the results essentially, as they generally occurred at different stations in different periods. The actual numbers of day fallen under each pair of given divisions of sum of kp indices and of rate occurrence of whistlers, are shown in Table 3a and the probable numbers

Table 2. Coordinate and Observation period

Observatory	Geom. Coord.	Obser. Period 1957
Toyokawa	24.5° N 203.5 E	1 Aug. - 30 Dec.
Wakkanai	35.3° N 206.0 E	1 Aug. - 30 Dec.
Brisbane	35.6° S 227.0° E	1 Aug. - 30 Dec.
Adelaid	44.9° S 212.5° E	4 Sep. - 30 Dec.
Hobart	51.6° S 224.6° E	1 Aug. - 30 Dec.
Macquarie Island	61.1° S 243.1° E	1 Aug. - 30 Sep.

Table 3. Correspondence between sum of kp and rate occurrence on same day

a. Actual numbers of day

		Sum of kp			
		0–10	10–32	32–48	48<
Rate per day	0–9	5	8	1	2
	10–49	33	57	19	7
	50–99	1	7	7	0
	100<	1	3	3	0

b. Probable numbers of day

		Sum of kp			
		0–10	10–32	32–48	48<
Rate per day	0–9	4.0	7.9	3.0	0.9
	10–49	28.5	56.2	22.5	6.8
	50–99	3.8	7.4	3.0	0.9
	100<	1.7	3.5	1.4	0.4

Table 4. Correspondence between sum of kp (on two days in advance) and rate occurrence

a. Actual numbers of day

		Sum of kp			
		0–10	10–32	32–48	48<
Rate per day	0–9	5	8	3	0
	10–49	29	60	19	4
	50–99	2	6	5	2
	100<	0	2	2	3

b. Probable numbers of day

		Sum of kp			
		0–10	10–32	32–48	48<
Rate per day	0–9	3.9	8.1	3.1	1.0
	10–49	26.9	56.7	21.6	6.7
	50–99	3.6	7.6	2.9	0.9
	100<	1.7	3.5	1.3	0.4

of day are shown in Table 3b, which are obtained assuming no correlation between both quantities. For the rate occurrence on each day the largest one is adopted among six observatories. From these results any clear correlation is not seen, but, if anything, it is rather negative. However, if the value of each kp is taken one or two days in advance, the correlation changes slightly positive. Tables 4a and 4b are obtained for kp two days in advance. In this case it will be noticed that high whistler activity has a tendency to occur on magneticaly active days, but it does not occur on quiet days. This result agrees with what have been reported. But this correlation is not so marked and that whistlers are observed on quiet days, therefore, generally, the charged particles coming from the sun on solar active days are not likely to be the constant origin of the ionzation.

Recently, Dugey (1955) presented another view. According to him, the outer atmosphere is consisted of fully ionized hydrogen at a temperature, 1,500°k, in thermal and

gravitational equilibrium and in dynamical equilibrium with the ionization in interplanetary space. This temperature is estimated from measurement of escape of helium. This is a very probable conception, because measurements of polarization of light suggest a continuously distributed ionization in space between the outermost part of sun's corona and the interplanetary space near the earth and that the constituent of this ionization is believed to be proton, as it is the most abundant substance in sun's corona. And an expression for the distribution of ionization is derived by him as $N=N_s \exp(2.5\ r_0/r)$, where N_s is the density in free space distant from the earth, and is taken to be 600 cm^{-3} by Storey, following results obtained by Siedentopf et al (1953) from measurement of zodiacal light, r_0 is the radius of the earth and r is the distance from the center of the earth. In connection with this theory, an available method to detect the presence of ionized hydrogen in the outer atmosphere, was presented by Storey (1956). This method is based on a theory that proton affects on propagation time (t) of instantaneous frequency (f) of whistlers and this causes a departure from the simple dispersion law that a quantity $t \cdot f^{1/2}$ is independent on f. And the departure is detectable at frequencies small enough to be comparable to the proton gyro-frequency, accordingly, if proton exist in the outer atmosphere, a measured curve of $t \cdot f^{1/2}$ will deviate from a constant value or it will agree with a theoretical curve calculated, assuming a proper distribution of ionization density. But, as at high frequencies there are also departure owing to the electron gyro-frequency, (measured curve) must be compared with complete dispersion curve including both effects.

Following this method, we tried to detect the proton in the outer atmosphere, using short whistlers observed at Toyokawa and Wakkanai, which were pure and well defined in a frequency range between about 8,000 and 700 c/s. Dungey's distribution seems to produce reasonable magnitudes of dispersion for whistlers observed at higher latitudes. But it is too small to cause observed values of dispersion at lower latitudes, for instance, in space above height of 300 km, it produces only dispersion of magnitude 18 $sec^{1/2}$ for a whistler propagating to Wakkanai. Consequently, distributions adopted in this calculation are obtained in the same way as used in § 2. The results are given in Figs. 3 and 4. In each Figure, A is a measured curve of $t \cdot f^{1/2}$ against f, and B is theoretical one calculated assuming that proton begins to exist above the level of 300 km height. The results obtained are enough to confirm the presence of proton in the outer atmosphere. Accordingly,

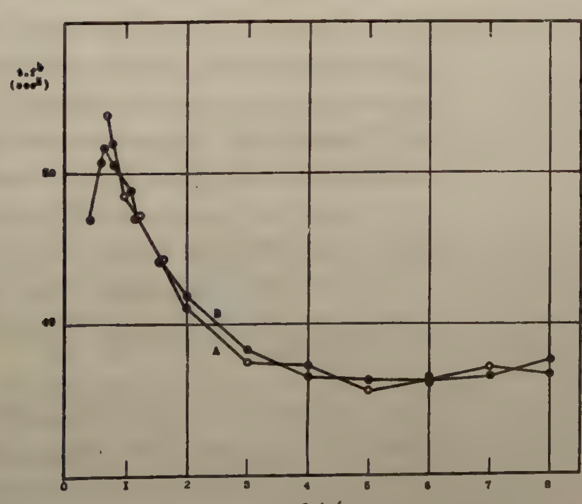

Fig. 3. Comparison of dispersion curves between observation (A) and theory (B), 24 Dec. 1957, 1605 J.S.T. Wakkanai.

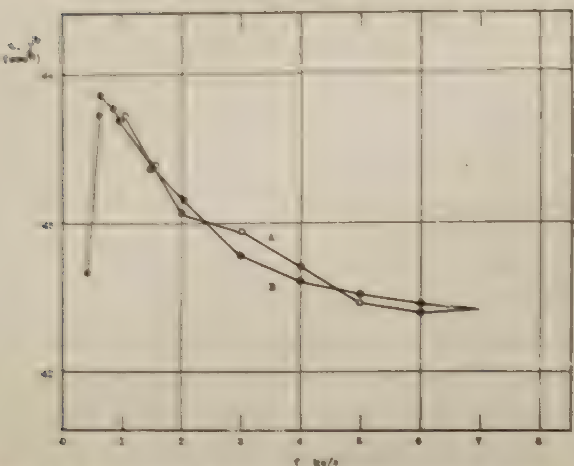

Fig. 4. Comparison of dispersion curves between observation (A) and theory (B), 20 Feb. 1957, 1715 J.S.T. Toyokawa.

the outer atmosphere composed of proton becomes more probable, and the ionization seems to be consistently connected with that of interplanetary space.

Thus, this result greatly supports a hypothesis recently provided by many workers, that the solar corona stretches out beyond the earth's orbit and it is connected with the earth's outer atmosphere. Further, another proof for this hypothesis was obtained by Allcock and Morgan (1958) from a study of correspondence between sunspot number and time delay of long whistlers measured from preceding atmospheric click. On examination through one year, they discovered a signiffcant correlation that monthly averaged values of time-delay change lagging one to two months with sunspot activity. This perhaps means that the ionization density in the outer atmosphere varies, lagging during that time, according to the sunspot activity.

The reason why Dungey's distribution is acceptable at higher latitudes, while it is not at lower latitudes, may be that the ionization in the lower part of the outer atmosphere is not only composed of ionized hydrogen, but also composed of ionized nitrogen and oxigen which are in thermal and gravitational equilibrium.

Thus, the dispersion observed at lower latitudes becomes greater than those obtained from Dungey's distribution, while the contribution to dispersions from this additional ionization may be small at higher latitudes, for in this case the greater part of propagation path lies in comparatively high altitudes, where the additional ionization becomes rarefied. Further, this view is quite favourable to explain the diurnal variation of dispersions seen at lower latitudes. Because the decrement of electron density caused in region 2 during from evening to midnight, described in the previous section, can be reasonably ascribed to a diminishment of electron density in that region owing to recombination and attachment processes after the sunset. As the decrement of electron density was small in region 3, the nitrogen and oxigen atmosphere may be greatly reduced in space higher than 1,500 km.

Here, one queston will arise why whistlers do not occur every day in spite of sufficient ionizations in the outer atmosphere existing all the times. The reason may be that at lower latitudes attenuations are greater, condition of total reflection is more ready to be formed and signal to noise ratio is smaller, while at higher latitudes, besides attenuations, lightning strokes are rare.

§ 4. Conclusions

Although locations of ray paths of whistlers can not be precisely decided, consequently the quantitative results may contain some uncertainties, and more data required for the statistical results, the followings may be concluded at this stage of study.

The regular ionosphere extends at least to the height about 1,500 km, which produces diurnal variation of dispersion of whistlers observed at lower latitudes, and the distribution of ionization is usually regular. This regular distribution of ionization produces whistlers of pure tone also at lower latitudes. But, during magnetic storms the regularity seem to be disturbed.

In space higher than this level, the outer atmosphere consists of ionized hydrogen, and this ionization is consistently connected with that of interplanetary space. And in this region the distribution of ionization appears to form a state of fibres along the earth's magnetic field, which produces swishes of multiple component at higher latitudes. At lower latitudes, the reason why whistlers are not observed every day, is perhaps due to propagation conditions, i.e. attenuation and total reflection, and at higher latitudes it may primarily due to lack of lightning strokes.

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Discussion

Maeda K.: Among informations obtainable from whistlers, the most desired one is a shape of distribution of electron density in the outer atmosphere, and at the same time the ray paths should be decided according to Fermat's principle to make the distribution more exact. But, it will be supposed that the modified group ray refractive index necessary for whistlers propagating to high latitudes, will make the application of Fermat's principle to decision of the ray paths, very difficult.

Outsu J.: As we specially intended to make the cause of the ioniztion in the outer atmosphere clear, electron densities were roughly estimated within limits enough to this purpose. However, we recognize the importance of getting an exact knowledge of the distribution.

Maeda K.: Though the ionization density has been thought to vary continuously from the outer atmosphere to the adjacent interplanetary space, this seems improbable, because discontinuites in physical properties have been theoretically expected between the two spaces.

Outsu J.: Exact data of electron density from nose-whistler will make this point clear to some extent.

2. Hydromagnetics in the Earth's Outer Atmosphere

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Abstract

The studies on the hydromagnetic interactions of the ionic exosphere with the geomagnetic field are reviewed. Considering the various hydromagnetic interactions, it is shown that the geomagnetic dipole field and the earth's atmosphere are confined within the cavity with the radius of the about from six to ten earth's radii, and hydromagnetics in the outer atmosphere are reduced to the electrodynamics for the thin transition layer between the interplanetary gas and the earth's exosphere.

1. Introduction

Now the aspect of the outer atmosphere (the region between the ionosphere and the interplanetary gas) is gradually taking away the veil of its mysterious character by observations of zodiacal light (Siedentopf et al., 1953), analysis of dispersion of whistling atmospherics (Storey, 1953) and by rocket flights including the launching of artificial earth satellites (Allen, 1956). On the other hand, the theory of hydromagnetics that studies the interaction between the magnetic fields and moving, electrically conducting fluids, has been in development in some years. Grounded on these circumstances, hydromagnetic behaviour of the outer atmosphere has drawn considerable attention for study with relation to the geomagnetic disturbances, cosmic ray, auroras and solar-terrestrial relations.

In this paper the survey of the investigations for the physical characters and of the electrodynamics of the outer atmosphere will be presented. The studies relating to the disturbance (say, hydromagnetic oscillations in the outer atmosphere) are not treated here.

2. Physical Characters of the Outer Atmosphere

The density of the atmosphere must decrease with increasing height and the frequency of collisions between particles will become smaller and smaller correspondingly. Ultimately we shall reach the extremely rarefied region where collisions are almost negligible and many upward moving neutral particles coming from the denser regions below will return under the influence of gravity, and few of them with hyperbolic orbit will escape from the earth. This region was called the fringe region of the atmosphere or the exosphere, mainly in the sense of the escaps of gas (neutral atoms) from the terrestrial atmosphere (Mitra 1952).

Theoretical study on the physical nature of the inner exosphere which consists of mainly neutral atoms was carried out by Spitzer (1951). The base of the exosphere is the region from which collisions send out the particles populating the exosphere and down into which most of the exospheric particles fall after a few minutes of free flight. He defines the middle of the region wherein a particle starting upward may reach the exosphere without further collision as the "critical level". Since the time which an individual atom spends in the exesphere is too short for ionization, dissociation, recombination, or other process to occur, the velocity distribution will be nearly Maxwellian at all heights and will be characterized by the temperature T_c at the critical level, with the exception of the escape particles, and diffusion equilibrium exists above the level where number density is about 10^9 particles/cm^3, whose height above the earth's surface is probably between 300 and 400 km. Above this level the density of the heavier particles will fall off more sharply than that of the lighter atoms. From consideration of the escape of helium, Spitzer estimates the temperature T_c of 1500°K for the isothermal exosphere.

The height of critical level is depend on collisional frequency between particles and for the neutral exosphere a value of h_c somewhere between 500 and 1000 km. (corresponding to the density of 3.5×10^7 particles/cm^3) is given. For ions and electrons the exosphere begins at a higher altitude because of the collisional cross-section between charged particles is far lager than that for neutral atmos by distant encounters resulting from electrostatic forces. In determining the distribution of charged particles the earth's magnetic field must be taken into account, and it turns out that this simplifies the problem because it prevents the charged particle from escaping. Considering the strong rigidity of the earth's field, it is likely that the ionic exosphere will extend to far greater distance from the earth's surface than that of the neutral one, and will form the outer exosphere which connects to the ionized interplanetary gas.

Considerable interest for the study of this region was stimulated by Dungey's pioneering works from theoretical side (Dungey, 1954). After his investigations the physical character of the ionic exosphere is as follows. The motion of charged particles in the presence of magnetic field is resticted within the spiral motion around the line of force, if there are no collisions between particles. The radius of the spiral for a proton with the thermal velocity corressonding to 1500°K is never more than $6.5\cdot10^{-4}H^{-1}$ km., and, since the geomagnetic field is approximately uniform over many kilometers, the conservation of magnetic moment of a proton is nearly valid for $H<10^{-4}$ gauss. The distribution of exospheric particles which soar up into the exosphere from the dedser region is controled by the distribution at the critical level by Liouvill's theorem, but, for charged particles there are many orbits which lie entirely above the critical level. This is caused from a fact that when a charged particle moves in the direction of increasing field strength, due to constancy of the magnetic moment its velocity component $V_\perp$ being perpendicular to field $\boldsymbol{H}$ increases at the expense of its velocity component $V_{/\!/}$ parallel to $\boldsymbol{H}$, and eventually, $V_{/\!/}$ becomes zero and the particle is turned back along the line of force. The distribution of particles in these

orbits is determined by collisions above the critical level. The particles can enter or leave such orbits only at collisions, and if the distribution in the other orbits, which passes through the critical level, is Maxwellian specified by temperature T_c in a steady state, there will be also a complete thermal distribution in the ionic exosphere.

From the requirement that the Maxwellian must be a solution of the stationary Boltzmann equation for the rotating gas without collisions, we have the following conditions (Chapman and Cowling, 1952):

i) temperature is uniform,

ii) the mean motion is a rigid rotation, irrespective of the presence of magnetic field,

iii) rot $(\boldsymbol{E}+\boldsymbol{V}\times\boldsymbol{H})=0$; magnetic field is axisymmetric and rotates rigidly with the matter,

iv) there is a diffusive distribution of density

$$n=n_0 \exp\left[-\frac{m}{KT}(\chi_0+\chi+\frac{e}{m}\Psi)\right],$$

where χ_0 is the centrifugal, χ the gravitational and the Ψ electrostatic potential.

The electric field $-\boldsymbol{V}\times\boldsymbol{H}$ requires a space charge density of the order of 8×10^{-7} electrons/cm^3 which will be found to be very much less than the electron density in the exosphere and therefore, there will be a validity of quasi-neutrality of charges. Due to the diffusion equilibrium the proportion of light elements increases with height in the ionic exosphere. The centrifugal force is relatively weak as compared with the gravity within the distances of about 8 earth radii, and the density of neutral atoms with atmic weight W varies as exp $(5W/R)$ for the uniform temperature of 1500°K, where R is in units of the earth's radius. Therefore, the density of neutral hydrogen atmos does not vary by more than a factor of $e^5(=148)$ between the extremities of the exosphere, and if convective equilibrium prevails up to a height where the concentration of H atom is 5×10^5 particles/cm^3 (Spitzer 1951), the density at the level of 10 earth radii becomes about 5×10^3 particles/cm^3. For charged particles, the effect of Pannekock-Rossland electrostatic potential which reduces the atomic weight by half, is introduced and the density of H^+ ion varies as exp $(2.5/R)$.

Apart from the diffusion equilibrium, the distribution of the density of electrons in the exosphere are obtained by several workers. Analysing the dispersion of whistling atmospherics, Storey (1953) obtained an electron density of about 400 electrons/cm^3. Maeda and Kimura (1955) made a more precise study using the ray path theory for propagation of whistlers and estimated the values of $10^4\sim10^2$ electrons/cm^3 at distances from thousand kilometers above the earth to several earth radii. From the study of the geomagnetic pulsations and of the hydromagnetic oscillations in the ionic exosphere, Jacobs and Obayashi (1958) presented a model of the ion distribution up to distance of about 6 earth radii. Radio observations from the satellites show an electron density of $10^3\sim10^2$ electrons/cm^3 for the outer ionosphere with altitudes of 2000~3000 km (Al'pert, 1958). These results may be nearly consistent with one another and this ionic exosphere may connect with the ionized interplanetary gas with an electron density of 600 electrons/cm^3 (Siedentopf, 1953).

3. Hydromagnetic Interactions of Ionic Exosphere under the Geomagnetic Field and Formation of the Outer Atmosphere as a Magnetic Cavity

A feature, which is very important for the mechanical behaviour of the outer exosphere, is that the kinetic energy of thermal motion of particles (gas pressure) is very much less than the magnetic energy of the dipole field up to a distance about 10 earth radii and magnetic field in this region is nearly current-free since there is no force being comparable with the magnetic pressure in stationary state. Macroscopically, due to the large magnetic Reynold's number the gas will rotate rigidly with the lines of force of the dipole field. It seems likely that the macroscopic hydroynamic equation and the relation of rot $(\boldsymbol{E}+\boldsymbol{V}\times\boldsymbol{H})=0$ are valid. However, in the region out of distance larger than about 10 earth radii from the surface, the kinetic energy of rigid rotation and gas pressure are comparable order of magnitude with the magnetic energy of the dipole field. Since the interaction between the field and ionized gas may be largest when there is an equi-partition of energy between the magnetic field and the others of gas, we have now a circumstance that a strong hydromagnetic phenomenon may be possible in the outermost part of the exosphere which is the boundary of the earth's atmosphere connecting with the interplanetary gas (I–P gas), and the field in this region may be distorted from that of dipole distribution.

Dungey (1954) showed that a magnetic cavity with the radius of about 9 earth radii, wherein the earth's magnetic field is confined, is produced through the Chapman-Ferarro process if there is a relative motion of the order of the earth's orbital velocity of 20 km/sec between the I–P gas with the density of 600 protons/cm^3. and the earth. The geomagnetic field will be distorted by the current flowing in the surface layer of the cavity, but, as the field resulting from this current is of the order of 4×10^{-4} gauss, it is too small to be detected at the ground. Similarly, in order to interprete the cosmic-ray cutoff with magnetic rigidity less than 1.5 BeV, Hoyle (1956) suggested that at the distance of about 10 earth radii from the surface, where the magnetic energy is comparable to the kinetic energy of I–P gas, there is a strong interaction between the earth's dipole field and the interplanetary stream, and beyond this distance gross modification form dipoler from of field must take place.

Although Dungey pointed out that the earth's orbital motion is the most dominant factor for the hydromagnetic interaction. On the other hand, from the fact that the shape of the surface of equal density of I–P gas obtained by the observations of zodical light is alleged and flattened (Öpik, 1954), there is a posstibility that I–P gas near the earth's orbit rotates about the sun with the earth. It is uncertain that whether there is a relative motion corresponding to the earth's orbital velocity between the I–P gas and the earth. If the magnetic cavity is produced by the interaction between the dipole field and the earth's orbital mtion, this motion will be decelerated by the collisions of I–P particles with the cavity. But, by rough estimation (Tamao, 1959), this deceleration is negligeble during the age of the earth. In this manner, the relative orbital motion, if exist, may be qualified for a possible cause of the geomagnetic

distortion but its geometrical configuration will be very complicated. Taking into account the rotation of the earth, this configuration of the cavity will become nearly axial symmetry except for the contribution due to the inclination between the axis of rotation and of the geomagnetic dipole.

On the distortion of the outer geomagnetic field, Simpson (1956) pointed out the westward shift of geomgnetic equator of the order of 45° from the analysis of cosmic-ray particles with low energy, and suggested that the hydromagnetic interaction of the rotation of the inclined magnetic dipole field with the ionized I–P gas may be a cause of the westward drag upon the magnetic lines of force. On this point, Maeda (1956) discussed the possibility of shearing distortion of the magnatic equator in the outer atmosphere and showed that owing to the induced fields generated by the rotation of the equatorial dipole in the ionized stationary gas, the dip equator will be made to shift westwards in the outer atmosphere. However, his calculation includes an error in that the component of rotating equatorial dipole is taken as a time-independent field in the referring stationary coordinates system. Although it should be noted that the discrepancies between the dipole predictions and the experimental observations of low energy cosmic-ray intensities and cut-off momenta may be accounted by introducing the earth's surface field with the anomalies (Rothwell, 1958), however, at the fringe region of the ionic exosphere the distortion from the dipoler form may still be expected from the present views of hydromagnetics.

Chapman (1957) proposed a model that the I–P gas near the earth's orbit is the extention of the outer solar corona and its temperature near the earth is of the order of $10^4 \sim 10^5$°K (the possible largest value is 2×10^5°K) under the assumption of conductive equilibrium of heat. In his model the effect of the solar magnetic field is not taken into account, but if we consider the flatterned shape of I–P gas the direction of the lines of force of the solar field will be nearly radial within this flatterned region. Then, his model does not need appreciable modification if the sun has its general field. Considering the above circumstance, it seems that the earth's exosphere is a relatively cold plasma with the temperature of 1500°K which is surrounded by a hot plasma of temperature of $10^4 \sim 10^5$°K. If we assume that the density of both plasma is nearly equal, then, owing to the pressure balance at the boundary surface it becomes necessary that current flows within the transition layer between both regions and the resulting Maxwell stress compensates the difference of gas pressure between them. The values of external gas pressure corresponding to $T=10^5$ and 10^4°K for $n=10^3$ protons/cm are 2.8×10^{-8} and 2.8×10^{-9} dyne/cm², respectively and this pressure balances the magnetic pressure at the of $8\sim10$ earth radii from the ground. Tamao (1957) treated the corresponding model for the spherical earth with the inclined dipole under assumption that there is a mechanical balance of the magnetic force with the gas pressure gradient in the transition region between the I–P gas and the rigidly rotating exosphere, and showed that a strong toroidal field with magnitude larger than that of the polodal one exists in this region. He connected this toroidal field with the westward shift of the geomagnetic equator, but now this interpretation is clearly

incorrect.

Considering the radially streaming "solar wind" with the particle density of 500 protons/cm^3 and a velocity of 500 km/sec suggested by Biermann (1951, 1957) as a relative motion between the earth and the ionized coronal material, Parker (1958) obtained a value of 6 earth radii for the extent of the earth's dipole field, and showed that the boundary between the solar wind and the earth's dipole field is unstable and flutters in the wind with frequencies of about one cycle per second and less (Dessler, 1959).

The problem of the cavity formation was also discussed from the study of the rotation of the ionic exosphere (Tamao, 1959). If the space surrounding the earth is vacuum, the whole of the earth including its atmosphere will rotate as a rigid body in the first approximation. On the other hand, the earth with its atmosphere is immersed in the rarefied highly conducting I–P gas. If the dipole distribution is extended into the I–P gas, then in stationary state the I–P gas will also rigidly rotate with the lines of force, and its rotational velocity becomes very large in the far distant regions from the earth's surface. This condition introduces the rotational instability at the levels with the distance larger than about ten earth radii from the center of the earth; since rotational instability of an infinitely long cylinder with the axial magnetic field occurs, if the kinetic energy of rotational motion conforms to the order of that of magnetic field. Therefore, the rotation of the outer atmosphere and the geomagnetic dipole field should be terminated within the distance smaller than this order, and a non-uniform rotaion occurs in the transition layer between the rigidly rotating exosphere and the stationary I–P gas. As is well known, what is called T$_2$-toroidal field $\boldsymbol{H}_\varphi$ is produced through motional induction of the non-uniform rotaion with the dipole-like field $\boldsymbol{H}_r$, and the outward transport of angular momentum of the order of $(4\pi)^{-1} r \sin\theta H_r H_\varphi \mathrm{cm}^{-2}\,\mathrm{scc}^{-1}$ occurs in such a way that the distribution of angular velocity in a conducting gas will be towards uniform by magnetic stress. Taking into account such circumstance, the rotation of the earth will break down during the age of the earth unless the radius of the rigidly rotating cavity is larger than about 10 earth radii. If the kinetic energy of rotational motion is comparable with the magnetic energy, the dimensional length of the region, where the Hall term in the generalized Ohm's law has the comparable magnitude with the motional induction, is of the order of $L \simeq (\mathrm{m}_i/4\pi ne^2)^{1/2}$. This is the wave length of proton plasma oscillation and is of the ordes of 7.2×10^5 cm for the electoron-proton plasma with density of $n=10^3$ particles/cm^3.

As was stated in the above paragraphs, the hydromagnetic interaction of the ionic exosphere with the geomagnetic field may reduce to the phenomena in the most outer part of the exosphere (transition region between the I–P gas and the exosphere). On discussing the electrodynamics in this region, collisions between charged particles can be neglected since the mean free path of particle is decisively larger than the thickness of the transition layer. If the concentration of particles is so small that the mutual interaction between them are negligible, the orbit of a charged particle will be determined when field is shecified (say, Störmer theory for the motion of a slingle

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This situation is similar to that of the ...

in the former the field is confined within the cavity ...

through the surface layer of this cavity may ...

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particle in the dipole magnetic field). On the other hand, in our case the density is fairly so large as to take into account the mutual interaction between particles which appears mainly as the poralization field retaining quasi-neutrality of charges. This electric field ties strongly the motion of ions with that of electrons. The rough calculation using a one dimensional model for the boundary phenomena shows that magnetic field is shielded within the distance of about $l \simeq [m_i m_e / 4\pi n e^2 (m_i + m_e)]^{1/2}$ which is of the order of 1.7×10^4 cm for $n \sim 10^3$ particles/cm by the Hall current flowing in this layer, and the total pressure, including magnetic pressure, is balancing on the boundary surface. The ratio of space charge density to that of electrons is approximately equal to the ratio of Alfvén wave velocity for the electron gas to the velocity of light, and is almost negligible in the ordinary conditions. If we take the value of about 10 earth radii for the radius of the magnetic cavity, the thickness of the transition layer is a little larger than the radius of gyration of electron, but smaller than of proton. Thus, the motion of ion is less affected by the presence of magnetic field than that of electron with the exception that the ions are tied with electrons throgh the space charge electric field. This situation is similar to that of the surface phenomena of plasma in fusion reactor (Rosenbhith, 1957) except that there is no magnetic field within constricted plasma, while in the former the field is confined within the cavity and the lines of force passing through the surface layer of this cavity may across the ionospheric region on some latitude, and the geomagnetic disturbances and the auroral display may be connected with this situation.

Every possibility discussed above will contribute more or less to distortion of the geomagnetic field and formation of the cavity. Due to a large radial gradient (also, possible existence of a strong toroidal field) which may be present in the transition layer, the diffusion of charged particles of low energy, being across through such layer, may be almost impossible. It will also be expected that the radial limitation of the dipole field discussed above may introduce a different effect for the cosmic-ray and the auroral particles from that experienced by non-limited dipole field. Our present knowledge concerning the electromagnetic conditions in the outer atmosphere is yet speculative, but the recent and the future successful launching of artificial earth satellites will give a solution to this difficult problems. In concluding, the writer wishes to express his gratitude to Prof. Y. Kato for his kind encouragement in this study.

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Discussion

Matsuura N.: Does an unstability occur on somewhere of the surface of the cavity?

Tamao T.: Yes. It may be likely that the surface of the cavity corresponding to the polar regions will become unstable by a strong inward magnetic force caused by the westward surface current, and auroral particles shall penetrate into the lower atmosphere during the main phase of magnetic storm.

Maeda K.: It is an important problem to determine the shape of configuration of the cavity by any means, theoretically or experimentally. Could you calculate the geometry of the cavity for a relatively simple model? I think that the shape of the cavity will not be a spherical but a something which has hollows near the polar regions, say like a pumpkin.

Tamao T.: The quantitative determination of the shape of the cavity will necessarily introduce the dificult non-linear characters. I will expect the result of the successful launching of the earth satellites.

3. The Acceleration of Particles in the Outer Atmosphere

By Tatsuzo OBAYASHI

Hiraiso Radio Wave Observatory, Radio Research Laboratories

Summary

By the recent successful launching of Pioneer III and IV, there has been brought up a new evidence indicating the existence of regions trapping high energy particles in the earth's outer atmosphere (J.A. Van Allen and L.A. Frank, Nature, **183** 430–434, 1959). These are two distinct zones of intense flux of energetic particles of the order of million electron volts, the inner zone is situated a few thousand kilometer above the earth's surface, while the outer zone is at the distance of 3~4 earth radii.

It is the aim of this paper to suggest a possible mechanism producing such high energy particles in the outer atmosphere, though there have already been proposed several other mechanism by different authors. In the present paper it is considered that the energetic particles being produced in the earth's outer atmosphere rather than they are injected from the outside and being trapped by the geomagnetic field.

For this case, the Fermi mechanism of accelerating praticles in regions of plasma agitated by hydromagnetic waves (E.N. Parker, Astrophys. J. **111**, 1206, 1958) is appropriate. It has been shown elsewhere that the rate of energy increase of particles by the Fermi acceleration is given

$$\frac{dW}{dt}=W/\tau_F \quad ; \quad \tau_F=\frac{\lambda_0 w}{V^2}$$

where τ_F is the characteristic time of the acceleration, w is the particle velocity, V and λ_0 are the velocity of hydromagnetic waves and its wave length. The maximum energy of particles is limited by the time t_0, the escape time of particles from the agitated region of dimension L_0, and is expressed by

$$W=W_0 \exp (t_0/\tau_F)$$

where $t_0=\frac{\lambda_0}{w}\left(\frac{L_0}{\lambda_0}\right)^2$ and W_0 is the energy of thermal ions in the outer atmosphere. Assuming that $W_0 \sim 10$ ev, $w \sim V \simeq 3000$ km/s, $\lambda_0 \simeq 6000$ km and $L_0 \simeq 20000$ km, it can be shown that the maximum enegry of particles attained by the Fermi acceleration is about 1 mev. This is well of the order of particle energy found in the experiments.

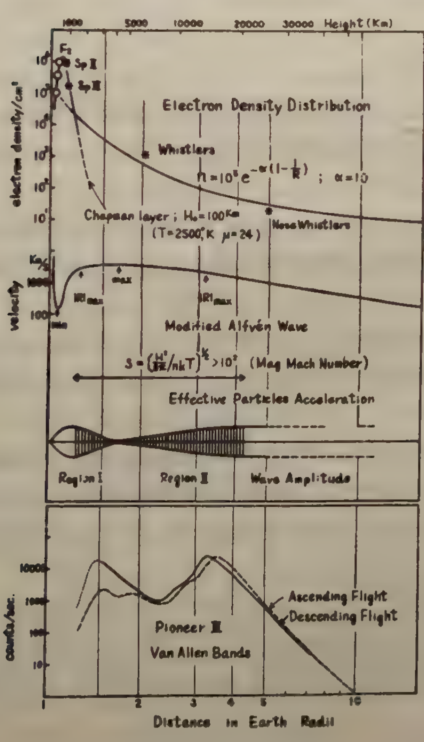
On the other hand, the effectiveness of the Fermi acceleration depends on two factors; one is the amplitude of hydromagnetic waves and the other is the compressibility of the plasma. There are considerable evidences that the hydromagnetic waves excited

by solar corpuscular streams exist in the outer atmosphere, and they may be observed as geomagnetic pulsations (T. Obayashi, in this issue). The mode of such hydromagnetic oscillations depends on the ionic density and the geomagnetic field distributions in the outer atmosphere. Using the current model of the outer atmosphere shown in the Figure (due to rockets and whistler observations), the velocity of a longitudinal hydromagnetic wave is computed

$$V=\sqrt{\frac{2kT}{m}+\frac{H^2}{4\pi nm}}$$

where H, T, n, m, and k are the geomagnetic field intensity, temperature, ion density, ion mass and the Baltzman constant respectively. There are two regions where the wave velocity decreases with height. As has already been pointed out by Dessler (J. Geophys. Res. **63**, 507, 1958), in these regions downward travelling hydromagnetic waves will be reflected back, and thus it is likely that the hydromagentic waves may exist as a kind of standing wave in the outer atmosphere. Therefore one possible mode of hydromagnetic oscillation will be the one which has its nodal point at the top of the ionosphere and at the height of 5000 km above the earth's surface, and its wave amplitude may have a form as shown in the Figure.

It has also been suggested by Parker (Phys. Rev. **109**, 1328, 1958) that the Fermi acceleration mechanism is operative so long as the hydromagnetic waves can maintain sharp fronts or crests. This situation is possible only when the compressibility of gas bearing magnetic inhomogeneities $[\Delta H^2/8\pi nkT]$ is large. In the Figure the region of the magnetic Mach number larger than 10^2 is indicated by the line.



It can be understood now that there are two regions where the situation is favorable for the particle acceleration process of Fermi-type, i.e., both wave amplitude and wave compresibility are large. The region I exists at the height between 1000 km ~3000 km and the region II is of the order of 10,000~20,000 km. Comparing with the result of Pioneer III by Van Allen et. al. (bottom of the Figure) and the one of theoretically expected by the present investigation, it is found that the agreement is generally good. Therefore it may be concluded that the hydromagnetic oscillations in the outer atmosphere are responsible for producing the high intensity flux of energetic particles surrounding the earth.

4. Morphology of ssc and ssc*[1]

By Siro Abe

Geophysical Institute, Tokyo University

Abstract

In general we may consider that it is very rare that ssc* is not observed in any part of the world at the time of sudden commencement of magnetic storms. The electric current-systems for the world distribution of the preliminary impulse and the main impulse of the sudden commencement vectors are derived. These current-systems will be situated in the earth's upper atmosphere except the current representing the world-wide increase in the horizontal component of geomagnetic field of extra-terrestrial origin. The dependency of occurrence freqency of ssc* on local time and latitude can reasonably be explained by the characteristic modes in these current-systems. A theoretical interpretation of ssc and ssc* phenomena will be possible by combining the merits of various different theories.

1. Introduction

Typical magnetic storms usually begin with a world-wide sudden commencement. Sometimes the sudden commencent is preceded by a preliminay kick of small amplitude on the magnetogram.

According to the recent resolutions on the morphological terminology adopted by IAGA Com. No. 10 for rapid geomagnetic variations, the following definitions are used for the beginning part of magnetic storms.

ssc : A sudden impulse followed by an increase in activity lasting at least one hour. The more intense activity of the storm may appear immediately or it may be delayed a few hours.

ssc* : This is similar to an ssc; except that the sudden impulse is immediately preceded, on at least one component, by one or more small reverse oscillations. In case the reverse movement has approximately the same amplitude as the principal movement, it will be reported as ssc.

Various interesting characteristics of the ssc and ssc* have been studied for a long time by many researchers. In the present paper, a brief summary of the morphological results by these investigators is presented, and a theoretical interpretation of these phenomena is also suggested.

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[1] Contribution from Division of Geomagnetism and Geoelectricity, Geophysical Institute, Tokyo University. Series II, No. 88

2. Reviews of analysed facts for the sudden commencents of magnetic storms

2–1. *Simultaneity of the beginning time of ssc and ssc* over the world.*

The sudden commencement of magnetic storms has been recognized to take place simultaneously all over the world within a few minutes (Adams 1880, 1881; Ellis 1892; Angenheister 1913; Chree 1910, 1914; Chapman 1918). The more detailed examinations show that the difference of the beginning times at each stations are less than 30 seconds or a few seconds in some cases (La Cour, Rodés, Okada 1933; Imamiti 1938; Ferraro-Parkinson-Unthank 1951; Nagata 1952).

When a magnetic storm begins with a typical sudden commencement, ssc* is generally recorded in some part of the world, while ssc is observed in the remaining region. According to the works by Imamiti, Nagata and other authors, the so-called main impulse of ssc* preceded by preliminary impulse takes place almost simultaneously with ssc at other stations.

2.–2. *Relative occurrence frequencies for ssc* and ssc.*

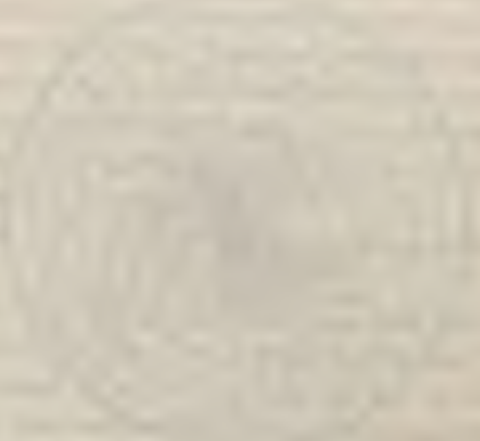
According to the recent examination of the ratio of occurrence number of ssc* to the total number of sudden commencements (ssc* and ssc) at some individual stations, the ratio is 0.48 at Lerwick (Watson and McIntosh 1951) and 0.55 at Greenwich (Newton 1948).

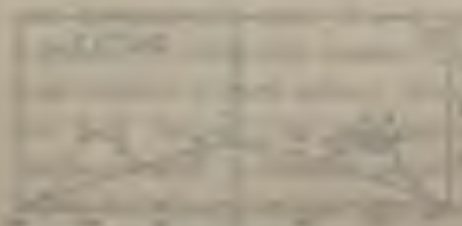
In the next place, the occurrence frequency is compared for two cases of magnetic storms, where the storms are classified for convenience according to whether ssc* is recorded at least at one station or at no station so far as all the available report is examined. Although this classification is too artificial and of vague physical significance because of its dependency on the distribution of observatories, this conventional analysis would suggest how often ssc* is observed from a world-wide standpoint. Even by examining the reports from five U.S. stations, Sitka, Cheltenham, Tucson, San Juan and Honolulu, the ratio of occurrence frequency of the former case of storms to all cases is relatively of a high value, 0.63 for 1946–1948 and 0.60 for 1946–1948 (Nagata 1952, Nagata and Abe 1955). The similar analysis by means of the geomagnetic and solar data published in "Journal of Geophysical Research" shows that the ratio is as high as 0.85 for the period of 1949–52, while it reaches 1.00 for July-Sept., 1958.

The results mentioned here indicate that ssc* is recorded at least somewhere over the world in most cases of the sudden commencements of magnetic storms. In other words, it scarcely happens that ssc* is not recorded over the world.

2.–3. *Equivalent current-system for the world-wide distribution of ssc's and ssc*'s*

T. Nagata and S. Abe (1955) studied the world-wide distribution of preliminary impulse of ssc* for some selected magnetic storms, and they derived a world-wide current-system corresponding to the distribution of horizontal vectors of the preliminary impulse (p.i.) of ssc*, which is reproduced here as Fig. 1. The distribution of p.i. vectors is rather systematic in high latitudes, depending on both local time and geomagnetic latitude. According to recent analysis, the horizontal vector of p.i. of ssc* near the geomagnetic equator seems to be enhanced in the daytime.





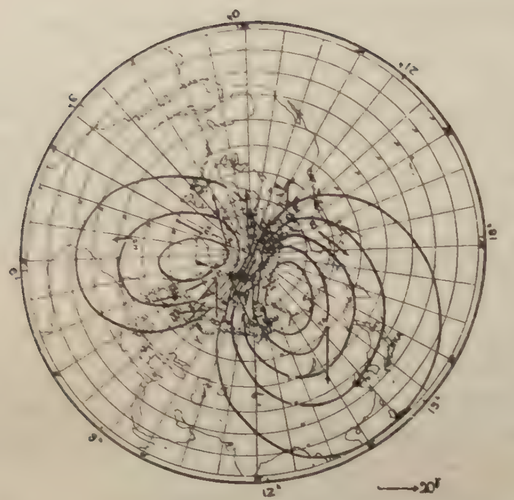


Fig. 1. Distribution of the equivalent current-system for the preliminary impulse of scc* and the current arrows for the p. i. of scc* at 06h 25m UT on May 29, 1933 after Nagata and Abe (1955) (viewed from above the north pole; 10,000 amp. flow between successive stream lines).

On the other hand, the current system for the main stage of ssc is obtained by T. Obayashi and J.A. Jacobs (1956, 1957), where the system is divided into two parts, its zonal- or D_{st}-part denoted by D_{st}^c and the remaining part D_s^c, both of them being reproduced here as Fig. 2. As the separation of D_{st} and D_s is made only mathematically, it is necessary to pay special attention to interpret the physical mechanism for the current distribution.

As for the existing height of the current-system, it is reasonable to suppose that the electric current corresponding to a local geomagnetic change flows near the earth's surface. From this reason, the current-system for the p. i. of ssc* is believed to be in the earth's upper atmosphere. The current-system for D_s is also considered to flow in the ionospheric region.

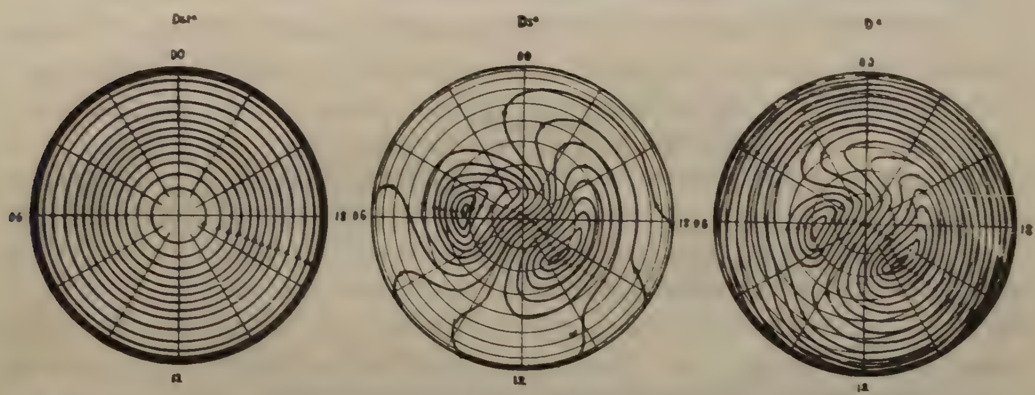


Fig. 2. Electric current-systems of D_{st}^c-, D_s^c. and D^c-fields for ssc or the main impulse of ssc* of magnetic stroms by Obayashi and Jacobs (1956, 1957) (viewed from above the north pole; 10,000 amp. flow between successive stream lines).

Concerning the height for D_{st}^c current-system, the following remark is worth noting. A rather intense zonal current along the auroral zone in the D_{st} current-system seems to be owing to an intense eastward current in some small restricted area in the auroral zone. The equatorial

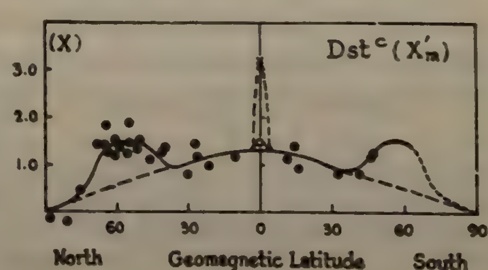


Fig. 3. Latitude distribution of D_{st}^c (X) of ssc or the m. i. of ssc* of magnetic stoms by Obayashi and Jacobs (1956, 1957), modified slightly by the author.

enhancement of zonal current flow seems to originate from a daytime enhancement of the increase in amplitude of the ssc vector near the geomagnetic equator reported by Sugiura (1953), which will be mentioned again later. These two anomalies in the longitudinal distribution of D_{st}^{c} indicated in Fig. 3 should originate in the earth's upper atmosphere, although the basic latitudinal distribution of ssc vectors is likely to be explained by the fact that an extra-terrestrial uniform magnetic field is applied at the time of ssc in addition to the current flow in the ionosphere.

2.–4. *Change in current-system during the development of sudden commencements of magnetic storms.*

The duration times of the preliminary impulse and of the following main impulse have been examined by several researchers (Newton 1948; Ishikawa 1950), and the results are that the duration of p. i. is about a minute, and that of m. i. is about 3 minutes in average. It is also proved from examination of quick-run records at various stations that the preliminary impulse of ssc* is observed immediately before the characteristic beginning of storm at places, where the sudden commencement is registered as ssc.

From these results one may consider the following change in the geomagnetic field at the very beginning of magnetic storms, *i.e.* a p. i. field is set up at first and disappear after about 1 minute, and then the appearance of m. i. field follows immediately, the growing time of which is about 3 minutes. According to a study of the change in the mode of equivalent overhead current-system within a few minutes during the sudden commencement made by T. Oguti (1956), he suggested that an electric dipole appearing near the geomagnetic pole corresponding to the polar anomalous field seems to rotate clockwise during the course of rapid sudden commencement, and this progressive change will explain a systematic dependence on local time of type of SC magnetogram traces, and also of the particular distribution of the preliminary reverse impulse of ssc*.

2.–5. *Local time dependency of occurrence frequency of ssc and ssc**

So far as the occurrence frequency of sudden commencements (including ssc and ssc*) at an individual station is concerned, they take place more frequently in the afternoon with a maximum around 13 h in local time, and a minimum occurrence around 8 h (Moos 1910; Rodés 1932; McNish 1933; Newton 1948; Ferraro, Parkinson and Unthank 1950, 1951). It is of course a rather paradoxial fact that the occurrence frequency of world-wide sudden commencements has a special dependency on local time common to each station. Some authors e. g. G. Ishikawa (1950), S. E. Forbush and E. H. Vestine (1955) published an objection that there is no such a tendency as mentioned here. It has been noticed that the average amplitude of ssc observed in middle latitudes varies also with local time, showing maxima at midnight and midday and a pronounced minimum around 8 h (Ishikawa 1950; Yokouchi 1953; Obayashi and Jacobs 1956, 1957). It is worth noting that the average amplitude of s.s.c. vectors is the smallest around 8 h in local time when the minimum occurrence of s.s.c.'s is found. The direction of the sudden commencement vector shows also a particular dependence

From these results we may consider the following change in ...

disappear after about 1 minute, and that the appearance of ... ...
tely, the growing time of which is about 3 minutes. According to a study of the
change in the mode of equivalent overhead current-system ... ...

on local time as examined by T. Yumura (1956) and others.

This characteristic dependency of the frequency, the magnitude and direction of ssc vectors or the main impulse vectors of ssc* on local time and latitude will be reasonably understood by taking account of the general mode of the world-wide current system for the sudden commencement. In middle latitudes around 8^h in local time, the D_{st}'-field is much reduced by the superposing D_i'-field than the other region of the same latitude, so that very small ssc's may perhaps be overlooked if the simultaneous record at other station is not examined. This will be a cause of the apparent dependency of occurrence frequency of ssc's on local time.

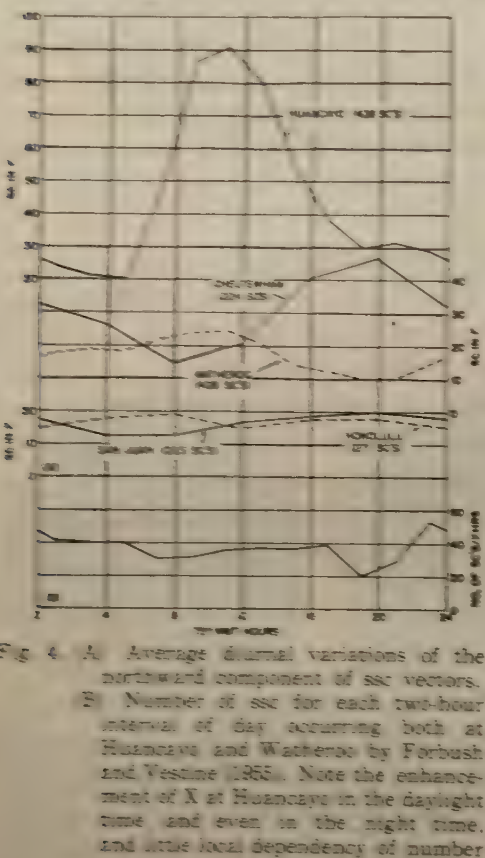


Fig. 4. A. Average diurnal variations of the northward component of ssc vectors. B. Number of ssc for each two-hour interval of day occurring both at Huancayo and Watheroo by Forbush and Vestine (1955). Note the enhancement of X at Huancayo in the daylight time and even in the night time, and little local dependency of number of ssc.

As for ssc*, the current-system for ssc* shown in Fig. 1 shows the dependency of occurrence and amplitude of ssc* on local time and geomagnetic latitude, and this is in accordance with the statistical appearance tendency reported by some authors (Newton 1948; Ferraro and others 1950, 1951; Nagata and Abe 1952, 1955), and even with its dependency on geomagnetic longitude when only some selected stations are examined (Ferraro and others 1950, 1951; Watson and McIntosh 1950; Yoshimatsu 1950; Yokouchi 1953; Jackson 1950; Chakraberty 1951. The results in the last two papers do not support Ferraro-Parkinson's expectance).

Another important problem is the equatorial enhancement of the horizontal sudden commencement vectors in the sunlit region near the geomagnetic equator (Sugiura 1953; Yumura 1954, 1956; Forbush and Vestine 1955), and this enhancement is especially large on days of large S_q variation (Forbush and Vestine 1955). For this fact one should consider an appropriate mechanism in the ionosphere for producing such an observed tendency.

2–6. Variation in the vertical component at the time of sudden commencements.

The geomagnetic variation in the vertical component at the time of ssc or ssc* is not systematic in spite of fairly regular distribution of horizontal geomagnetic change, as reported by many investigators (McNish 1933; Bartels, Heck and Johnston 1934; Barber 1948; Nagata 1951; Rikitake 1952, 1958; Fleischer 1954; Wiese 1954, 1956). This circumstance is found not only in the case of sudden commencements but

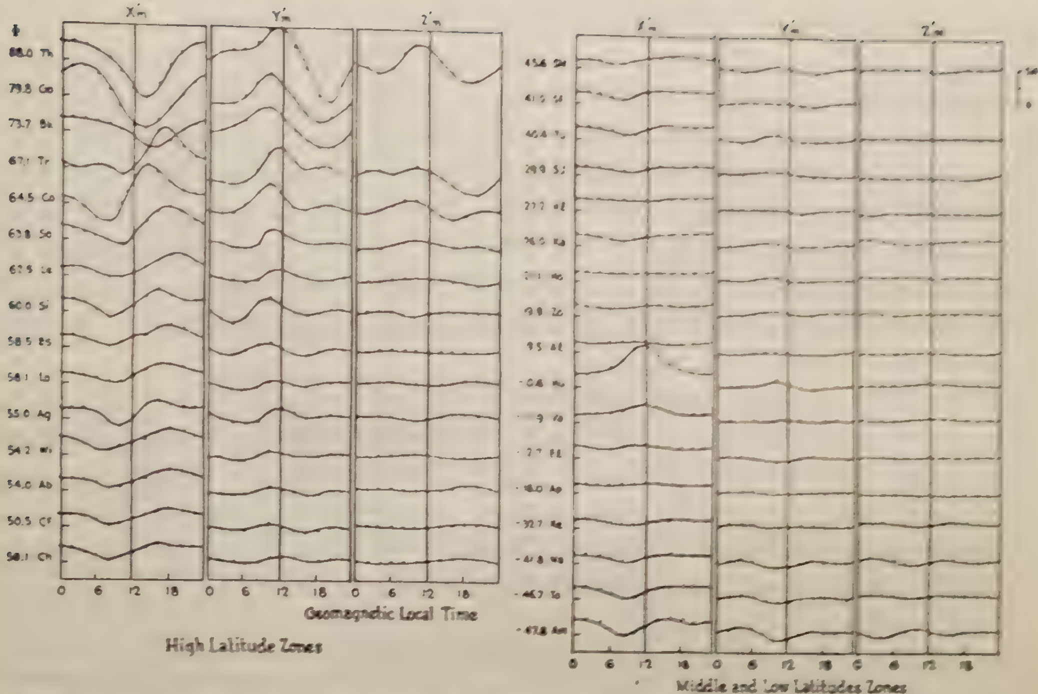


Fig. 5. Average diurnal variations of X'_m (geomagnetic north component), Y'_m (east component), and Z'_m (downward component) of ssc and m. i. of ssc* by Obayashi and Jacobs (1956, 1957).

also in short period variations in general including bay disturbances.

Since the geomagnetic change in the vertical component is strongly influenced by the electrical conductivity under the earth's surface, it is rather difficult to pick up the true distribution of vertical geomagnetic change of purely external origin (Yumura 1954; Obayashi and Jacobs 1956, 1957).

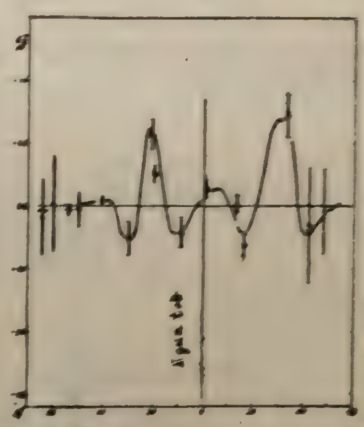


Fig. 6. The dependence on geomagnetic latitude of the distribution of the ratios of the vertical amplitude to the horizontal amplitude of the sudden commencement vectors by T. Yumura (1954).

3. A theoretical interpretation for ssc and ssc* phenomena

The interpretation of ssc and ssc* has been hitherto presented by many investigators (Chapman and Ferraro 1931, 1940; Chapman 1952; Ferraro 1952; Alfvén 1955; Singer 1957; Kato and Watanabe 1958; Obayashi and Jacobs 1957). Each theory proposed by these authors has its merit, but the definitive explanation for all the morphological structure of the ssc and ssc* phenomena seems not to be reached at present.

In the following it is tried to propose a possible mechanism for ssc and ssc* based upon various theories mentioned here and the criticism to these theories.

The approach of solar neutral ionized stream is of course presumed. The magnetic field inside the stream will be negligibly small. For the comment concerning the magnetic field inside the stream by Alfvén, a mechanism proposed by Petukhov (1958) seems to be promising. The electric current produced in the boundary layer of the coming solar stream when it reaches the vicinity of the earth will result in the world-wide ssc (or main impulse of ssc*) on the earth's surface as Chapman and Ferraro suggested. Although the presence of interplanetary matter is not taken into account in their original theory, this is not be so serious enough to cause the rejection of their theory. The approaching surface of the solar stream may be considered to be like a shock wave front as Singer suggests.

As for the propagation to the earth of produced magnetic field by the electric current flowing along the approaching surface of the solar stream, it will be possible from the following consideration in spite of Singer's objection owing to the shielding effect of the conductive gas in the space between the approaching front of solar stream and the earth. By means of Piddinton's expression (Piddington 1954) the field equations in e. m. u. in a medium moving with velocity v are

$$\nabla^2 H_x - \frac{\sigma_2}{\sigma_1}\frac{\partial}{\partial z}\, rot_x H = 4\pi\sigma_3\left\{\frac{\partial H_x}{\partial t} - rot_x(v\times H)\right\} - \left(1-\frac{\sigma_3}{\sigma_0}\right)\frac{\partial}{\partial y}\, rot_z H + c^{-2}\frac{\partial^2 H_x}{\partial t^2},$$

A similar equation in H_y,

$$\nabla^2 H_z - \frac{\sigma_2}{\sigma_1}\frac{\partial}{\partial z}\, rot_z H = 4\pi\sigma_3\left\{\frac{\partial H_z}{\partial t} - rot_z(v\times H)\right\} + c^{-2}\frac{\partial^2 H_z}{\partial t^2}, \tag{1}$$

under the condition $H=H_0+h$, $h \ll H_0$ where z-axis is taken parallel to H_0 (original field, being assumed to be uniform everywhere). σ_0, σ_1 denote the electrical conductivity of gas respectively along and perpendicular to the magnetic field, and σ_2 is the so-called Hall conductivity. In the present case, $\sigma_2 \simeq 0$, because the mean free path of gas particles is larger than the gyro-radius in the space from the approaching surface to the upper part of ionospheric region. Assuming the propagation of disturbance along x-axis and no variation along y-axis, the equation (1) can be reduced in this part of space as

$$\nabla^2 H_z = 4\pi\sigma_3\left\{\frac{\partial H_z}{\partial t} - rot_z(v\times H)\right\} + c^{-2}\frac{\partial^2 H_z}{\partial t}. \tag{2}$$

Considering the case in which h varies as $h_0 \exp i(\omega t + kx)$ and v does. k must satisfy

$$k^2 = -4\pi i\sigma_3(\omega - kv - kh) + \frac{\omega^2}{c^2}. \tag{3}$$

Taking $v \simeq 10^8$ cm/sec and $\omega = 2\pi/T = 2\pi/200$ sec^{-1}, and $\sigma_3 = 2\cdot10^{-25}$ e.m.u., then the first and second terms of the right-hand side of eq. (2) may be ignored, and it is said that the perturbing field h is propagated with the light velocity without remarkable attenuation.

In the vicinity of the earth, on the other hand, the shielding effect must be taken into account in the earth's atmosphere below the level where the mean free path and

the radius of gyration for charged particles are of the same magnitude. The region contributing to the shielding effect is the ionospheric region. After the results of examination of the shielding effect for the external magnetic field by Ashour and Price (1948), Sugiura (1948, 1950), the effect is not so large for variations with period of about 200 seconds, so that the external geomagnetic field can be observed also at the earth's surface with some reduction of amplitude and phase shift. Thus the world-wide increase of the horizontal component of geomagnetic storms, such as shown in the D_{st}^{c}-field in Fig. 2 except the anomaly near the auroral zone and geomagnetic equator, seems to be explained by the approaching of solar neutral ionized gas to the earth.

In the next place, the production of electric current in the earth's atmosphere responsible for ssc* and also for D_s^c-field is considered. The electric current-system in the ionosphere is considered to be caused by the impinging solar corpuscular stream upon the earth's atmosphere.

The induction current flowing on the surface layer has two foci where the retarding effect of the approaching solar stream is absent, and two incipient horns will come out from these points, as explained by Chapman and Ferraro. These horns will be extended to the earth's atmosphere. The rigorous mathematical treatment of this movement is very difficult. The surface of these horns is a shock wave front, and the cross section area of the horn becomes small as the earth's line of magnetic force converges near the earth. As a consequence, Singer showed the increase of velocity of impinging particles to the order of 10^9 cm/sec. Particles of this high velocity have enough energy to reach the level of the E layer and have also enough power to produce ionization. The arrival time of these particles along the horns at the ionos-

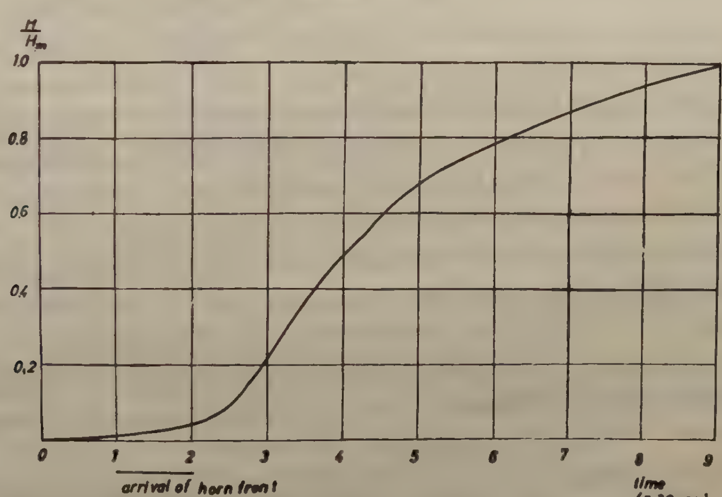


Fig. 7. The rise in the horizontal geomagnetic field H at the geomagnetic equator calculated by means of Nagata's treatment (Nagata 1954); In this estimation not only the distortion of the beam front but also the screening effect by the earth's ionosphere are considered. Note the time of the arrival of horn front at the ionosphere in high latitudes.

[illegible]

In the next place [illegible]

[illegible] [illegible] one and two [illegible] horns [illegible] out from these points, as explained by Chapman and Ferraro. These horns will be extended to the earth's [illegible]. [illegible] of the movement is very difficult. The surface of these horns is [illegible], and the cross section area of the horn becomes small as the [illegible] line of magnetic force converges near the earth. As a consequence Singer showed the increase of [illegible] of impinging particles to the order of 10^8 cm/sec. Particles of this high velocity

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following conclusions can be obtained.

1) It is very rare that all the magnetic stations over the world report the time of the sudden commencement

phere is estimated to be a little earlier than the time at which the world-wide increase of the horizontal geomagnetic field becomes noticeable as shown schematically by Fig. 7.

The electric current-system for p. i. of ssc* will be produced in the earth's upper atmosphere by a dynamo action with the ionization by particles impinging along the horns. The D_{st}^{c}-field illustrated by Fig. 2 will also be attributable to a dynamo action in the ionosphere, which is caused by the ionization of particles that come immediately after the vanguard particles. The particles may come out from the current bearing layer of the solar stream especially near the geomagnetic equator by a mechanism suggested by Martyn and Chapman in a ring current. In this case the gradient of the magnetic field just in the current bearing layer of finite thickness may play an important role.

Since the current flow in the current-systems for the p. i. and m. i. of ssc* differs in direction, the heights of electric current-systems for p. i. and m. i. may differ from each other. The progressive change in the magnetic field at the time of ssc* examined by Oguti seems to be a support for this opinion. The following point must be also examined. The shock wave does not always propagate along the magnetic line of force, and there may be some effect of the propagation transverse to the earth's magnetic field.

4. Conclusions

Summarizing various characteristics examined for ssc and ssc* phenomena, the following conclusions can be obtained.

(i) It is very rare that all the magnetic stations over the world report ssc at the time of the sudden commencement of individual magnetic storms, and we may consider that ssc* is almost always observed in some part of the world.

(ii) Main impulse of ssc* takes place simultaneously with the steep increase of the horizontal intensity at stations, where the commencement is recorded as ssc. The beginning time of ssc* in high latitudes corresponds to a slow increase in the horizontal intensity just preceding the abrupt steep change of ssc.

(iii) The dependency of occurrence frequency of ssc* on local time and latitude can well be expressed by the equivalent current-systems for the preliminary impulse shown in Fig. 1.

(iv) Local time dependency of occurrence frequency of sudden commencements and of their magnitude is explained by the presence of the non-zonal component of field (illustrated by D_{st}^{c}-field in Fig. 2).

(v) Current-system for p. i. of ssc* and some part of ssc field should originate in the earth's upper atmosphere.

There are of course many problems to be examined in future by means of much data of high quality. The examination of the world-wide progressive change of the geomagnetic field at the time of some typical individual magnetic storms will be especially worthy.

The theoretical interpretation of ssc and ssc* phenomena seems to be successfully made by combining the merits of theories proposed hitherto by many authors, although further treatment is of course desirable.

The author wishes to express his hearty thanks to Prof. T. Nagata for his kind guidance and advice, and to the members of the Society of Terrestrial Magnetism and Electricity of Japan for their encouragement and discussion. The writer's hearty thanks are especially due to Dr. N. Fukushima for his valuable advice and help in preparing this report for publication.

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Discussion

Kato Y.: How and when does the horn front of the approaching solar stream arrive at the ionosphere?

Abe S.: According to Singer's or my estimation, the front of horns arrives the earth 15~30 seconds after the initial formation of horns at the distance of several earth radii. At the time of arrival the world-wide increase in the horizontal intensity of the geomagnetic field is not yet noticeable, amounting to only a few percent of the total increase by ssc.

Yanagihara K.: Has the numerical ratio of the occurrence frequency of ssc* to that of ssc and ssc* any significant difference from the ratio for si and si*?

Abe S.: According to Ferraro and others (1951), these two quantities are almost equal.

Watanabe T.: As for the electrical conductivity in the space between the front of approaching solar stream and the earth, did you use the conductivity for alternating current?

Abe S.: For the case of magnetic field change with period of about 700 seconds corresponding to the growing time of ssc of 3 minutes, the conductivity for alternating current is reduced to that for direct current.

Hirono M.: Piddington assumes $\sigma_0 \sim \sigma_3$. Why is this assumption not used in your calculation?

Abe S.: The relation is valid only when one kind of charged particle, say electrons, make a predominant contribution to the electrical conductivity. In my calculation, the coexistence of protons and electrons is considered, so that σ_2 vanishes, and σ_3 is reduced to σ_1.

5. Some Remarks on the Morphology of Geomagnetic Bays*

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Abstract

The unequal occurrence frequency of positive and negative geomagnetic bays at various places over the world will be attributable to the condition that most cases of geomagnetic bays are polar elementary storms, especially negative ones, the typical or idealized disturbance field of which is represented by an overhead current-system composed of an intense westward current of narrow longitudinal width along the auroral zone and the counter current flow over the whole remaining part of the world. This result must be carefully taken into consideration when the average current-system for geomagnetic bays is dealt with. The systematic rotation sense of the disturbing force vectors of bays observed everywhere in middle latitudes, clockwise in the forenoon and counter-clockwise in the afternoon, is a result of the systematic progressive change in the overhead current-system during the course of bays. Some other important problems to be examined are also suggested.

1. Introduction

Geomagnetic bay are the most simple type disturbance of polar magnetic storms, and the comprehensive study of geomagnetic bays is of essential importance for investigating magnetic storms. K. Birkeland (1908, 1913) mentioned a fundamental polar disturbance in his monumental work, and he called it a "polar elementary storm". According to the present terminology in geomagnetism, the polar elementary storm is a geomagnetic bay itself. Since then many researchers have tried to clarify various interesting and important characteristics of geomagnetic bays, and some of them discussed the overhead current-system for geomagnetic bays in detail. The recent aeronomical study deals with not only geomagnetic records but also simultaneous ionospheric and auroral phenomena, and such a synthetic study serves greatly for the interpretation of the physical mechanism for geomagnetic bays.

In the present paper, the author tries to introduce a summary of the present knowledge on geomagnetic bays mainly from the morphological standpoint with special attention to the interpretation of current-system for geomagnetic bays, and some other remarks are also given.

2. Disturbing Force of Geomagnetic Bays in Moderate Latitudes

The disturbing force of a geomagnetic bay on a magnetogram is assumed usually to

* Contribution from Division of Geomagnetism and Geoelectricity, Geophysical Institute, Tokyo University, Series II, No. 89.

be the deviation of the geomagnetic elements from an interpolated curve connecting the undisturbed curves before and after the bay. The trace of the endpoint of the horizontal disturbing vector usually describes a loop during the whole course of a bay. In Fig. 1 such a trace of disturbing vector for the mean of a number of bays observed

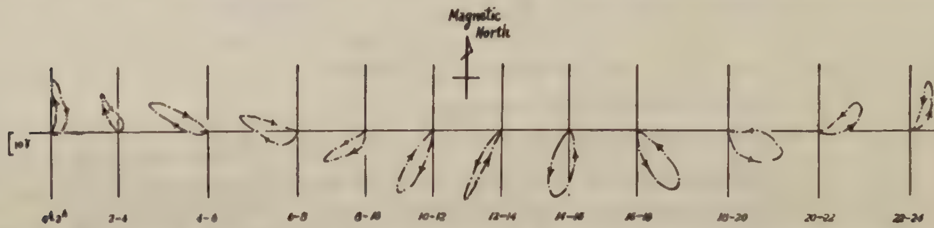


Fig. 1. Progressive change of the mean horizontal disturbing vectors of geomagnetic bays observed at Toyohara (After H. Hatakeyama).

at Toyohara (46°58′N, 142°45′E) during four years 1932–35 is illustrated, where bays are classified according to their local time of occurrence (Hatakeyama 1938). So far as the middle latitude region is concerned, the disturbing vector of geomagnetic bays shows a similar trace as shown here (Steiner 1921, Curto 1949, Fukushima and Ōno 1952, Rougerie 1954). The direction of maximum disturbing force or the direction of major axis of loops changes with local time, almost northward at about 2h in local time, westward in the early morning, southward in the early afternoon, and eastward in the evening.

The sense of rotation of the loop described by the endpoint of the horizontal disturbing force of geomagnetic bays is always clockwise in the forenoon and counter-clockwise in the afternoon. The numbers of bays observed in each two-hour interval in Fig. 1 are not evenly distributed. These are also the common statistical tendency for geomagnetic bays observed everywhere in middle latitudes. These characteristics are worth noting for interpreting the electric current-system in the ionosphere and its progressive change, about which the discussion is made in the following sections.

3. Overhead Electric Current-System for Geomagnetic Bays

A geomagnetic bay is not a local disturbance but a world-wide phenomenon in general. From the world-wide distribution of the simultaneous disturbance field of bays, an equivalent overhead current-system for geomagnetic bays can be drawn. An average current-system corresponding to the maximum stage of bays illustrated by Silsbee and Vestine is reproduced here as Fig. 2, where the system is referred to geomagnetic latitudes and local time, and its height is assumed to be 150 km above the earth's surface. The current-systems for bays by other researchers are of course similar to this current-system.

At a glance at this current-system for geomagnetic bays, we notice that it resembles the current-system for the famous idealized *SD*-field by Chapman (1935) except the phase shift of a few hours and the asymmetric distribution of current intensity of westward and eastward currents along the auroral zone. But the practical distribution

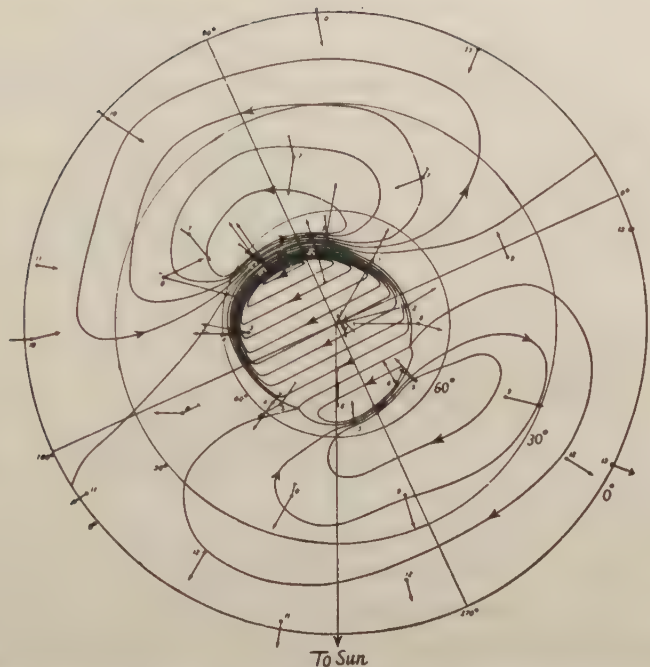


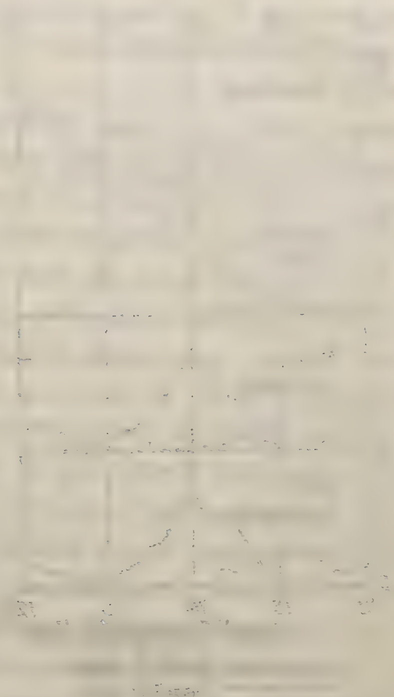
Fig. 2. An equivalent overhead current-system for geomagnetic bays drawn by H.C. Silsbee and E.H. Vestine (View from above geomagnetic north pole).

of polar disturbance field examined by Vestine (1938) shows that the real pattern of the polar part of current flow in the *SD*-field show the advance of a few hours in phase compared with the idealized one, while the phase in lower latitudes in the idealized *SD* current-system is proved by many researchers to be approximately correct. One may say that the equivalent overhead current-system for geomagnetic bays is quite similar to the atmospheric current-system of magnetic storm except the phase difference of about 4 hours in the current flow in lower latitudes. It is not yet certain whether this phase difference in the current distribution in lower latitudes has a fundamental physical significance in studying the mechanism for geomagnetic bays and for the *SD*-field.

We may intend to consider as a first approximation that geomagnetic bays are caused by the development and decay of such a current-system as given in Fig. 2. But even this simple consideration requires a qualitative correction described in the next section.

4. Qualitative Correction for the Current-System of Geomagnetic Bays Required from the Dependency of Occurrence Frequency of Bays on Local Time

In middle and low latitudes, the occurrence frequency of positive bays at night much exceeds that of negative bays in the daytime. So far as many investigators have examined, the ratio of occurrence frequency of positive bays to that of negative bays at a middle latitude station ranges 2~4 or more. Silsbee and Vestine (1942) gave a more careful frequency distribution, where geomagnetic bays are selected through the comparison of magnetograms at many stations of adequate geographical distribution over the world in order to avoid a small local disturbance, which is not a world-wide bay phenomenon in spite of its apparent bay-like trace on magnetogram. Their result of mean frequency distribution in the polar cap, auroral zone, middle and low latitudes is reproduced here in Fig. 3, in which the ratio of occurrence of positive and negative bays in middle and low latitudes is lowered down to about 3:2. On the other hand,



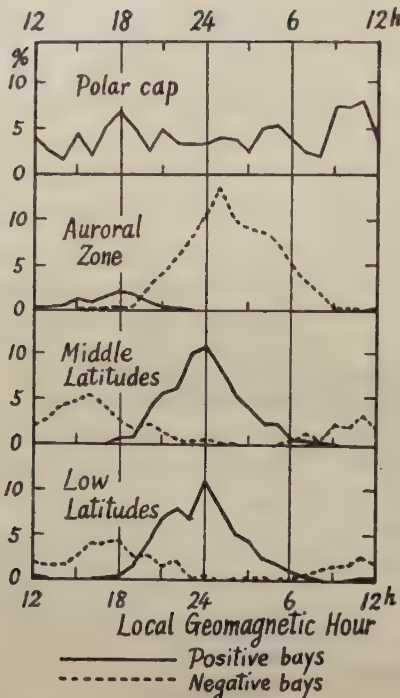


Fig. 3. Mean daily variation in occurrence frequency of geomagnetic bays in the polar cap, auroral zone, middle and low latitudes. Positive and negative bays are separately shown for the latter three regions (After H.C. Silsbee and E.H. Vestine).

negative bays outnumber positive bays in a proportion of 9:1 in the auroral zone, and this definitive significant difference is especially worth noting.

One cannot help considering many cases when the negative bays alone are observed near the whole circle of the auroral zone. Such a case is no more than the case of an absent eastward auroral zone. (A typical current-system for such a case is shown later in Fig. 4.)

In the current-system of Fig. 1, the number of geomagnetic bays used for drawing the westward auroral zone current much exceeds that for the eastward auroral zone. In other words, there are many bays without noticeable estward auroral zone current. One may say that the eastward auroral zone is obtained by averaging a small number of major bays, while the bays of moderate magnitudes without remarkable eastward auroral zone current are also taken into account for obtaining the density of the westward auroral zone current. Then it will reasonably be said that a real average mode of many individual geomagnetic bays should have the much reduced current density of the eastward auroral zone compared with that in Fig. 1. In lower latitudes the true average intensity of electric current having westward component corresponding to negative bays should also be reduced in intensity, because negative bays in lower latitudes are small in their occurrence frequency.

5. Current-System for Polar Elementary Storms

Polar elementary storms, which were first found by K. Birkeland, are nothing else but geomagnetic bays. He classified them into positive and negative perturbations, according to whether the dicturbing force increases or decreases the horizontal intensity of geomagnetic field in the auroral zone. His diagram of an idealized overhead electric current-system for a negative polar elementary storm is given in Fig. 5 (not his original but revised), which is the distribution of electric current lines on a conducting spherical shell when an electric dipole is situated along a latitude circle corresponding to the auroral zone, say 22.5° in polar distance (Nagata and Fukushima 1952, 1954; Fukushima 1953). When two dipoles of the same electric moment are situated symmetric with respect to the equator, the distribution of stream lines is of course also symmetric with respect to the equator. He reported that polar elementary storms occur rarely quite

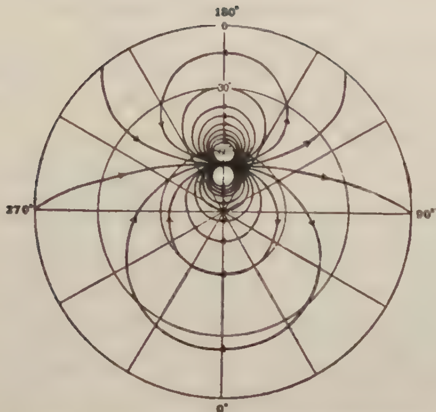


Fig. 4. An electric current-system for the (negative) polar elementary stom.

alone, but positive and negative storms take place simultaneously but in different districts as a rule. Their occurrence was found to be subjected to the relative position of the sun or local time ; negative storms on the morning and night sides of the globe with occasional extension along the auroral zone, while positive ones at the other side from noon to evening. In this case, the extension of negative polar elementary storms is as a rule much larger than that of positive ones.

This description for the occurrence tendency of polar elementary sto⁻ms is just the same as that for geomagnetic bays, which is indicated in Fig. 3. At the time of either positive or negative polar elementary storm, a positive bay is to be observed almost in half the total area of lower latitude regions, and it is also the case for negative bay. In other words, the statistical occurrence frequency for geomagnetic bays at many stations of uniform distribution in lower latitudes should show the nearly equal appearance frequency for positive and negative bays, even when negative polar elementary storms take place more frequently than positive ones. Thus the significant difference in occurrence frequency of negative and positive bays noticed only in the auroral zone may be reasonably understood.

The occurrence frequency of positive bays at night at a station in lower latitudes is always in fact slightly larger than that of negative bays in the daytime. This statistical tendency will be reasonably explained as follows. In the case of a simple negative polar elementary storm, or in general when the westward auroral zone current is much more intense than the eastward one, the electric current intensity at a certain latitude is more strong for the eastward current in the dark hemisphere than for the westward current in the sunlit hemisphere. This means that the magnitude of positive bay is larger than that of negative bay at the same latitude with the difference of 12 hours in local time. It may often happen that the negative bay in lower latitudes is overlooked, because the density of overhead westward current is much weaker than that of the eastward current flow corresponding to the positive bay along the same latitude circle, as will be clearly seen in Fig. 4, and further the existence of solar daily variation will cause a practical difficulty in detecting a small negative bay in the daytime. On the other hand the positive bay at night is easily detectable because the magnetic record at night shows a linear trace in undisturbed condition. Then it may be quite reasonable that the positive bays are picked up more frequently than the negative ones in middle and low latitudes, so far as the occurrence frequency is discussed for a single station.

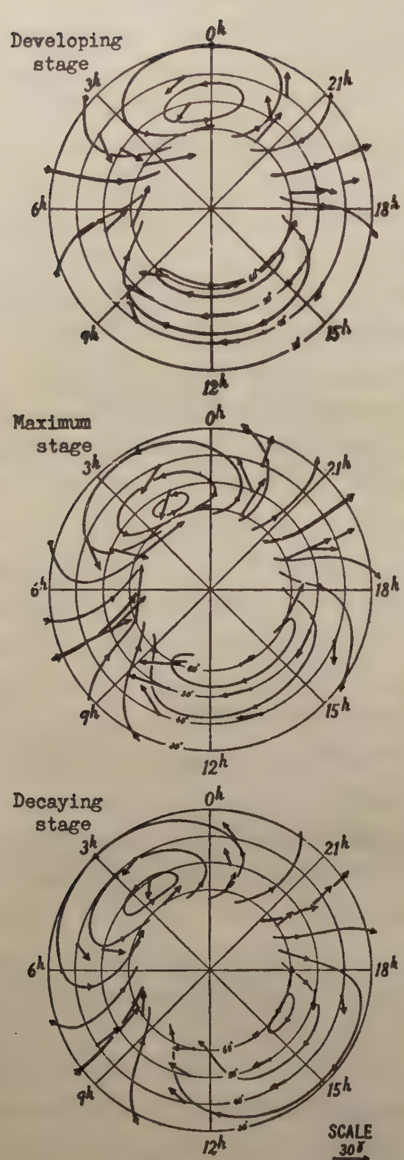


Fig. 5. Progressive change in the overhead current arrows and current-system for geomagnetic bays in middle and low latitudes.

6. Progressive Change of the Current-System for Geomagnetic Bays

Although a geomagnetic bay may be considered to be caused by the development and decay of such an electric current-system in the ionosphere as shown in Fig. 2 as a first approximation, a progressive change in the current-system should be taken into account in order to explain the systematic change in direction of the disturbing force vector during the course of a bay mentioned before and illustrated in Fig. 1, namely the endpoint of disturbing vector describes a loop, the rotation sense of which is clockwise in the forenoon and counter-clockwise in the afternoon everywhere in middle and low latitudes. The effect of the induced electric current flow within the earth cannot result in such an observational tendency, so far as the external electric current-system is assumed to keep its form with varying intensity (Lippmann 1955), and we have to think that the external current-system itself changes its form with time.

The systematic character of the change of the disturbing force of bays in middle and low latitudes is explained by the progressive change of the whole current-system for bays that the area of positive bay becoms narrower and that of negative bay becomes wider during the course of a bay. Moreover there is a slight tendency that the current-system shifts eastward a little on the whole as illustrated by Fig. 5 (Fukushima 1950, 1953; Fukushima and Ōno 1952). This systematic progressive change in the current-system is the cause of systematic rotation sense of the disturbing vectors of bays explained above.

7. Pulsations Accompanying Geomagnetic Bays

Pt type pulsations are very often found on magnetograms in middle or low latitudes at the beginning or in the developing stage of bays, but not in the decaying stage after the magnitude of disturbing force vector becomes maximum. This is also an important fact, and one may consider that this type of pulsation is caused by the

direct impinging of extra-terrestrial corpuscles upon the earth's outer atmosphere. Looking at the magnetograms for the later stage of bays, one may get the impression that the electric current-system decays without any external excitation.

8. Equatorial Ring Current and Geomagnetic Bays

At the time of polar magnetic storms the equatorial current ring is considered to be present in general. It is also an interesting problem, whether the ring current is also present at the time of geomagnetic bays. For this relation only some suggestive results have hitherto been presented, but a detailed study is desirable. The positive bay in lower latitudes is sometimes accompanied by the decrease in the horizontal intensity of geomagnetic field before and after the postive bay, and such a decrease must be clarified whether it is a world-wide one or not.

9. Concluding Remarks

In this report the present knowledge of geomagnetic bays is reviewed. From the occurrence tendency of positive and negative bays recorded at various places over the world, it is noticed that the electric current-system for most cases of geomagnetic bays is that for the polar elementary storm, a typical form of wich is illustrated in Fig. 4. This fact must be taken into consideration when the average current-system for bays such as shown in Fig. 2 is discussed. The systematic rotation sense of the disturbing force vectors of bays in middle latitudes, clockwise in the forenoon and counter-clockwise in the afternoon, is explained by the systematic progressive change in the overhead current-system during the course of bay.

The comprehensive examination of the progressive change in the world-wide distribution of the disturbance field of geomagnetic bays by means of much data of high quality is of course most desirable for the interpretation of the physical mechanism for polar magnetic disturbance. In this case the comparison of the disturbance field in the northern and southern hemispheres is worth examining, because we have poor knowledge of the disturbance in the southern hemisphere. Although the height of the intense auroral zone current is known to be 100∼150 km above the earth's surface (McNish 1938; Nagata 1950), the practical measurement of three-dimensional current distribution over the world in the upper atmosphere at the time of geomagnetic bays is especially valuable. At present only some provisional results of measurements by rockets and satellites have been published. Theories for geomagnetic bays are not mentioned here, but the dynamo action in the ionosphere with the anomalous increase in the electrical conductivity of the ionosphere in the auroral zone will be a fundamental cause (Rikitake 1948; Nagata and Fukushima 1952, 1954; Fukushima 1953; Vestine 1954; Obayashi and Jacobs 1957). The polar black-out and the ionospheric change in high latitudes observed at the time of bay (Wells 1947; Heppner 1954; etc.) will be a support for such an interpretation.

In concluding the author wishes to express his thanks to the members of the Society of Terrestrial Magnetism and Electricity of Japan for their encouragement and

In this region the present knowledge [illegible] magnetic [illegible]

[illegible]

This fact must be taken into consideration when the [illegible] given for [illegible] as shown in Fig. [illegible] is discussed. The systematic [illegible]

[illegible] in the afternoon, is explained by the systematic progressive change in the overhead current-system during the course of the [illegible]

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discussion. He is also very grateful to Prof. T. Nagata, under whose direction and with whose advice his works cited here were written.

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Discussion

Kato Y.: Do you mean that the polar elementary storms are included in the geomagnetic bays from the morphological standpoint?

Fukushima N.: Yes, I do. I believe that most cases of small geomagnetic bays seem like polar elementary storms.

Rikitake T.: As regards the decay of current-system for geomagnetic bays, have you calculated a decay time for such a current distribution over the world?

Fukushima N.: No, not yet. I think the practical decaying process of the current-system should be first examined in detail. When the records at middle latitude stations seem to show a slow decay of bay without additional disturbance, irregular variations are often found in the simultaneous records in high latitudes, and such a relation should be first clarified.

Watanabe T.: According to a recent estimation of the recombination coefficient in the ionosphere by Kamiyama, the decaying time of electric current in the ionosphere may be as long as several tens of minutes.

6. Some Characters of Geomagnetic Pulsation *pt* and Accompanied Oscillation *spt*

By Kazuo Yanagihara

Magnetic Observatory, Kakioka

1. Introduction

It is recently approved by many authors that geomagnetic pulsations are roughly classified into two or three groups. The Committee on Rapid Magnetic Variation and Earth-Current, IAGA, adopted the symbol *pt*, *pc* and *pg* as these groups. It is difficult to strictly define a group except *pg* which means giant pulsation, but the group, *pt* is considered to be the same as the night pulsations of G. Angenheister, Scholte and Veldkamp, and K. Yanagihara. In this paper some characters of *pt* are considered, especially, with respect to the associated shorter period oscillation *spt*, here named.

2. 11-year Variation of *Pt* Activity

One of the most remarkable characters of *pt* is that the 11-year variation of its activity is reversely proportional to solar activity (Yanagihara, 1957) (Fig. 1). In a statistical examination, the activity means the occurrence frequency of *pt* with amplitude which exceeds some limit value. If the limit amplitude is chosen as rather small value, variations of activity expressed by occurrence frequency are vague. The limit amplitude in the above statistical result, is determined as 20 mV/km in the earth-current at Kakioka (36°14′ N, 140°11′ E), so that the number of case is 100–200 in the sunspot minimum year, and 1–10 in the maximum year. In the IGY period, July 1957–Dec. 1958, the number of *pt*s selected by the above criteria, which are reported as category A to the No. 10 Committee, is less than 10.

To explain the reverse proportionality of 11-year variation of *pt* and solar activity, some considerations containing the screening effect of high conductive lower ionosphere were examined already (Yanagihara, 1957), but the ideas are not promising.

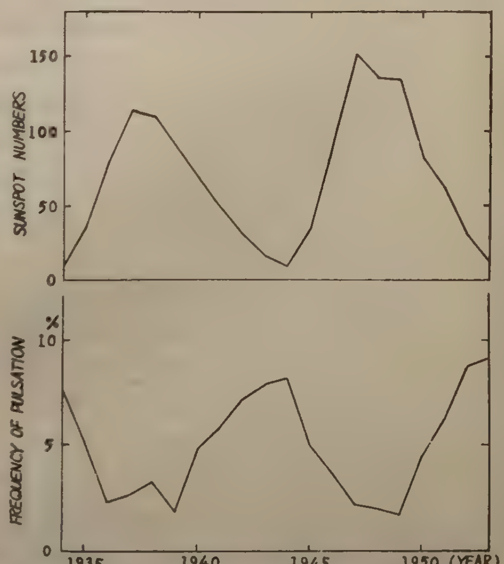

Fig. 1. 11-year variation of *pt* activity.

3. Pts and Magnetic Storm

It is known that *pt* is frequently accompanied with bay. On the other hand, if *pt* is not inclined to appear in the period of severe disturbance such as magnetic storm, the above reverse proportionality on *pt* and solar activity is deducible from a fact that magnetic storms are more frequently observed in the solar active years.

Statistical examination shows that probability of *pt* occurrence for each degree of disturbance up to $Kp=5$ or 6, increases linearly with Kp. As regards magtetic storm, probability of *pt* occurrence for large negative value of ΔH is not so different from mean values for whole degree of ΔH; ΔH is a daily mean departure of horizontal intensity from the monthly mean value. Then, the above assumption is not valid in the actual case.

4. Outer Atmospheric Oscillation and Pt Pulsation

Recently, possibillity of hydromagnetic oscillation excited in the Earth's outer atmosphere, has been considered first by Dungey (1954) and developed by Kato et al (1956). By them, two modes of oscillation exist in the outer atmosphere; one is the toroidal and the other is the poloidal oscillation. They considered that the poloidal oscillation is observed at the earth surface as *pt* and *pc* pulsations. It's oscillatory period was obtained by eigen value problem for a model of outer atmosphere of which ion density is constant in the whole region.

But in the actual case the ion density ρ decreases with increase of height from the maximum value in the ionospheric F_2-layer to some value of interplanetary space. On the other hand, geomagnetic field H also decreases according to R^{-3}, R is the distance from the centre of the Earth measured in the unit of Earth radius. Then, the Alfvén wave velocity $H/\sqrt{4\pi\rho}$ reaches its maximum value at some height except the case that the ion density ρ decreases more slowly than R^{-6}. Above the maximum region, Alfvén wave velocity gradually decreases as H decreases according to R^{-3}. The region of the maximum velocity forms a reflecting zone of Alfvén wave. The effectiveness of reflection is dependent upon the steepness of the maximum (or minimum) in the Alfvén wave velocity *vs.* height curve, because the reflection coefficient is $\{(A_1-A_2)/(A_1+A_2)\}^2$ at the boundary of the two media of which Alfvén wave velocities are A_1 and A_2, respectively.

If the reflection is effective, two different hydromagnetic oscillations will exist in (i) the region between the outer boundary of the outer atmosphere (that is the wall of the cavity) and the inner reflecting zone and (ii) the region between the inner reflecting zone and ionosphere, respectively.

In the actual case it is difficult to determine the Alfvén wave velociy *vs.* height curve, but some knowledge about the electron density in the outer atmosphere is obtained from the analysis of the whistling atmospherics (Maeda, 1956). On the other hand it was reported recently that the electron density up to 600 km height and its extrapolation up to 3,000 km level were calculated from the data of the earth satellite in USSR,

Sputnik I (1958). The electron density formula for vertical distribution by Sputnik bears a striking resemblance to that obtained by Maeda (1956) for the region up to 1000 km height from the whistler data.

By this model, by Sputnik I, the maximum zone of Alfvén wave velocity exists about in the 3000 km level and the reflection is fairly effective for the ratio of the maximum to the minimum of Alfvén wave velocity, which is considered to be 50–100. The periods of hydromagnetic oscillation in the two region above and below the reflecting zone are estimated as the orders of 1 min and 10 sec, respectively, by the calculation of double traverse time of Alfvén wave in each region.

5. Observed pt in IGY Period and Accompanied Shorter Period Oscillation spt

As the period of IGY is the sunspot maximum period, *pt*s selected by the severe criteria in § 2 are very few. Then, in this section, the criterion is loosened and 202 *pt*s are selected in the year 1958 from the induction magnetogram by loop at Memambetsu (43°55′ N, 144°12′ E). One of the most distinctive characters almost common to these 202 *pt*s is that the secondary oscillations with period 5–10^{sec} exist overlapping the main oscillation of *pt*. Here, this secondary oscillation

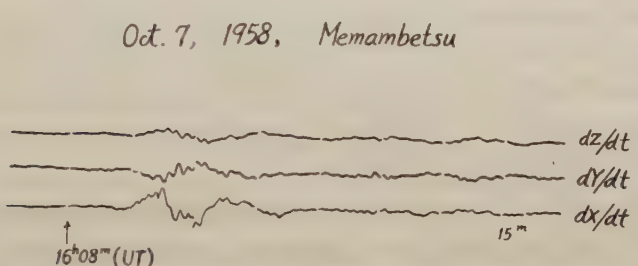

Fig. 2. An example of the accompanied short period oscillation, *spt*.

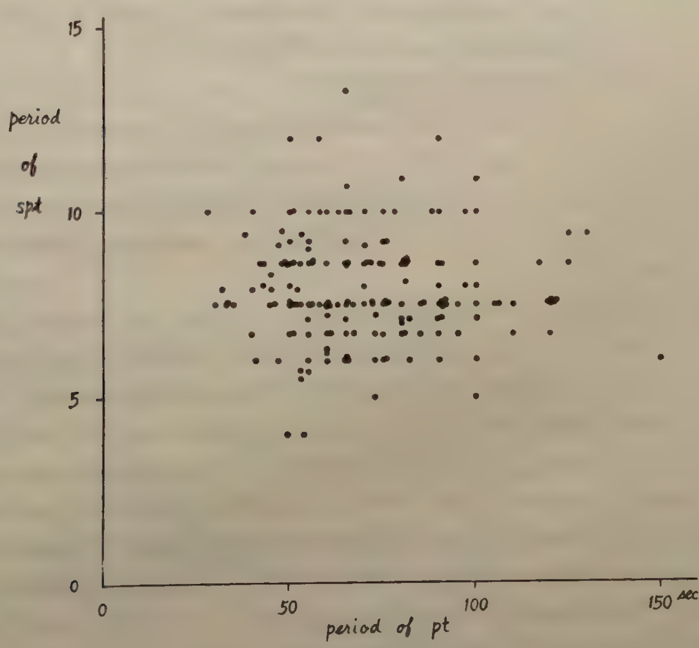

Fig. 3. Periods of *pt* and *spt*.

is named as *spt*. (Fig. 2).

Observational facts of *spt* are given as follows,

(i) Among the 202 *pt*s in the year 1958, 179 cases accompanied *spt*.

(ii) A *spt* starts almost at the same time as beginning of *pt*. If a continuous oscillation with period of 5–10^{sec} exists already before the beginning of *pt*, the oscillation grows more active.

(iii) Period of *spt* is almost in the range of 5–10^{sec}.

(iv) Period of *spt* does not depend upon the period of main oscillation of *pt*. (Fig. 3).

(v) A *spt* is found at the same time at the two observatories Memambetsu and Kanoya (31°25′ N, 130°53′ E) by induction magnetogram. The tellurigrams also show the same *spt*s. Then the *spt*s are not artificial phenomena.

(vi) In the sunspot minimum year, *spt*s are also found, but they are less active in this period when *pt* is very active.

(This result is obtained from the data of the Onagawa Magnetic Observatory)

(vii) Continuous oscillation with period 5–10^{sec}. The continuous pulsation *pc* is more active in the dayside, and its period is in the range of 10–40^{sec} (No. 10 Committee). On the other hand, in the night time a predominant continuous pulsation is the one with period 5–10^{sec}, that is the same as the *spt*'s period.

This characteristic pulsation *spt* is considered to correspond to the hydromagnetic oscillation in the region between the inner reflecting zone and ionosphere. On the other hand the main oscillation of *pt* is considered to be the one in the upper region.

6. 11-year Variation and Inner Reflecting Zone

The hydromagnetic oscillation in the region between the outer boundary and inner reflecting zone, is transmitted to the earth surface through the inner reflecting zone. Then, if the Alfvén wave velocity ratio A_2/A_1 is very small and the reflection is effective, the oscillation field in the upper region may not be transmitted to the earth surface and *pt* can not be observed. This is the case for the sunspot maximum period when the ion density of the exosphere is so high that the Alfvén wave velocity A_2 for the zone is low enough. In the same period, the associated pulsation *spt* may develop more actively.

On the contrary, in the sunspot minimum period, the reflection may not be effective so that the observed *pt*s are more active; or the reflecting zone becomes so vague that the hydromagnetic oscillation develops between the outer boundary and the ionosphere.

The hydromagnetic oscillation in the lower region may be less active in the period, but the occurrence of *spt* is not so extremely infrequent because of the less effect of the ionospheric screening which is effective for the period of *spt* such as 5–10^{sec}.

In concluding the author wishes to express his hearty thanks to Dr. T. Yoshimatsu, Director of the Kakioka Magnetic Observatory for his continuous encouragement on this study. His thanks are also due to Prof. Y. Kato who kindly permits to use the data of the Onagawa Magnetic Observatory.

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Discussion

Watanabe T. : What is the author's opinion on the variation of the Alfvén wave velocity and ion density of the exosphere in the course of the solar 11-year cycle?

Yanagihara K. : In the sunspot maximum periods, the ion density of the exosphere (from the upper part of the ionosphere to the about 3,000 km height) is increased, so the Alfvén wave velocity is decreased. On the other hand, in the region above that level the ion density is not increased so much and the decrease of the Alfvén wave velocity is not appreciable. Then, the ratio of the Alfvén wave velocity in the above region to that in the lower layer, is observed to increase in the sunspot maximum years, and *pt*s though intercepted are less frequently observed.

Outsu J. : From the data of the dispersion of whistler in the high latitudes, the ion density in the higher region than 3,000 km is considered to be changed according to the sunspot activity.

Yanagihara K. : The estimate of the amount of the increase or decrease, is the next problem in that case. If the ion density of the higher region is increased as much as the ionosphere, the ratio of the Alfvén wave velocity is not altered. In this case, some other considerations, for instance the difference of the Alfvén wave velocity itself in each layer, are necessary for the interpretation of the 11-year variation of *pt* activity, but interception by the midway layer is a promising supposition for low activity of *pt* occurrence in the sunspot maximum period.

7. Morphology of the Geomagnetic Pulsation*

By Tomiya WATANABE

Geophysical Institute, Faculty of Science, Tôhoku University

1. General Features of Geomagnetic Pulsations

We have many observational results obtained in the middle latitude region, whereas there are few observations in high and low latitudes stations. Besides, there is no complete observation made simultaneously in a sufficiently great number of observatories distributed on a world wide scale to obtain a definite geophysical picuture.

In the middle latitude region, we usually encounter two types of geomagnetic pulsations, named *pc* and *pt* respectively (Fig. 1.) The former is a series of pulsations

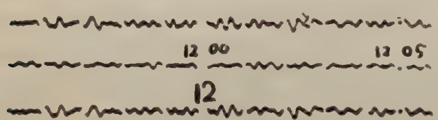

Fig. 1 a

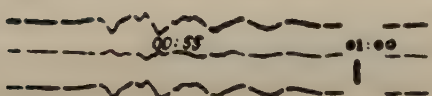

Fig. 1 b

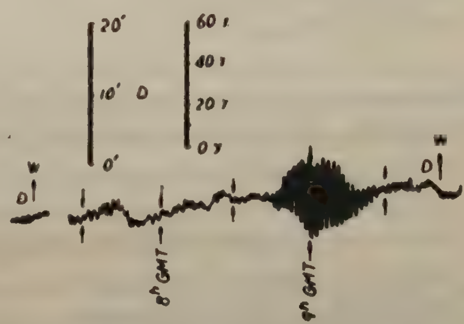

Fig. 1 c

Fig. 1a and 1b. Typical *pc* and *pt* pulsations recorded by the induction magnetometers at Onagawa Magnetic Observatory, near Sendai, Japan.
Fig. 1c. Typical giant pulsation observed at Abisko, Sweden (after B. Rolf).

appearing usually in the dayside of the earth, and lasting for many hours. The period lies, in general, between 10 and 60 sec, and the amplitude is, usually, of the order of $1/10\,\gamma$. On the other hand, the *pt* pulsation, which appears usually in the night-time, lasts ten minutes or more. The wave form is rather irregular compared to that of *pc*'s. A typical *pt* shows a series of damped oscillations. The damping time is of the order of several to ten minutes. The period is longer than that of *pc*, viz., 40 sec to a few minutes, and the amplitude is also larger than that of *pc*, that is, of the order of $0.5\,\gamma$. Very often, the *pt* pulsation preceds or accompanys a bay disturbance and disappears

* An abstract of a lecture read at this symposium, in which the author tried to establish laws governing pulsational phenomena in the geomagnetic field to be derived from observation. In cooporation with Prof. Y. Kato, the author made already such an attempt, based on an extensive survey of papers published (Sci. Rep. Tôhoku univ., Ser. 5, Geophys., 8, 157–185, 1957). In this lecture, the author took into consideration of the papers which appeared after our paper cited above.

after the maximum phase of the accompanied bay disturbance (Fig. 2). At the time of heavy disturbance, we cannot necessarily distinguish between the two types of pulsations.

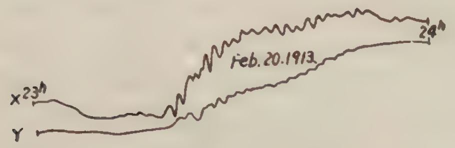

Fig. 2. Pt's accompanied by a bay disturbance (after T. Terada).

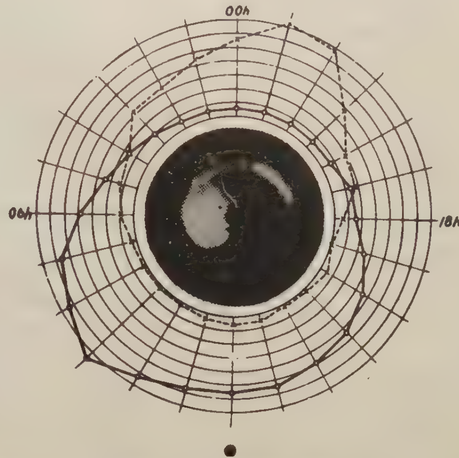

Fig. 3. Diurnal variations of the occurrence-frequencies of *pc*'s and *pt*'s. The solid line refoers to *pc*'s and the dotted one to *pt*'s (Onagawa Magnetic Observatory).

In the auroral region, many researchers paid their attention to a special sort of pulsations, named giant pulsation, of which period and amplitude are larger than those of the above two types of pulsations. The period is of the order of 1 minutes or more, and the amplitude amounts to several to some tens of gammas. Giant pulsations appear only several times a year. The general feature of the pulsation in the auroral region has not yet been analysed, perheaps because of its very complicated nature. We have few observations inside the auroral belt, except a pioneer study by means of an ordinary magnetograph, according to which such giant pulsations as in the auroral region do not appear in general, but weaker pulsations of shorter period are observed (Whitham & Loomer, 1958). We have yet no systematic study in the equatorial region.

Recently, some researchers (Troitskaya, 1953a, 1955; Chernosky et al., 1954) draw attentions to pulsations of which period is shorter than 10 sec, which were already noticed even with older instruments of registration (Harang, 1936; Sucksdoff, 1936). Those pulsations, which we shall name provisionally the geomagnetic vibration, have been observed at several stations in the different latitudes, with the results which are not necessarily coincidental.

2. Pc and pt Pulsations

In statistical study on the pulsations, we must always pay attention to the methods used for registration and statistics; according to different methods, we have often different results for the same phenomenon.

In order to examine the nature of a wave- or oscillation-phenomenon, we must read off the periods contained. The simplest method is to deal with regular pulsations only as in Terada's study (1917). It remains, however, unproved that regular pulsations would represent the general feature of the geomagnetic pulsation faithfully. In a more elaborate treatment, one should try to read off several pulsations overlapped with different periods. It may be rather labourious and mistakable to read with eyes as in

the cases of Holmberg (1953) and Angenheister (1954). Duffus and Shand (1958) make use of a harmonic analyser for this purpose.

In statistical studies on pulsations, the type between *pc* and *pt* has not necessarily been distinguished. In that case, one may suppose that pulsations of shorter period ~ 60 sec correspond to *pc*'s and those of longer period ~ 60 sec to *pt*'s.

(i) The mean amplitude of pulsation is greater, when the period is longer (Angenheister, 1954; Duffus and Shand, 1958). According to Duffus and Shand (1958), there are peaks around 1 and 2 minutes (Fig. 4). In the period interval from 5 to 30 sec, there appears a peak at 20 sec (Chernosky et al.). As a measure concerning the energy of pulsation, Angenheister (1954) introduced an index "Pulsationszahl," which is defined as a mean amplitude of a cartain frequency band multiplied with the duration-time in an unit time interval. Duffus and Shand named such a quantity "activity." The spectrum

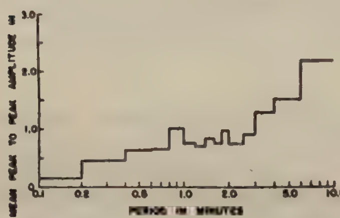

Fig. 4. Spectrum of amplitude versus period (after H. J. Duffus and J.A. Shand).

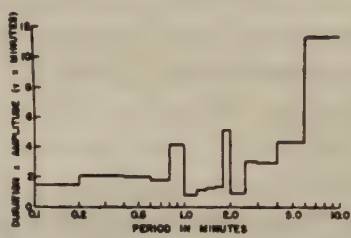

Fig. 5. Spectrum of activity versus period (after H.J. Duffus and J.A. Shand).

of activity against the period shows sharp peaks around 1 and 2 minutes and a slight maximum in the period interval from 0.2 min to 0.3 min (Fig. 5).

(ii) The period of those *pc* pulsations which we encounter most often lies, in general, between 20 and 30 sec. Eschenhagen (1897 a, b) already noticed in the end of the last century such pulsations which sometimes appear in the form of sinusoidal oscillation and named them elementary waves, convincing that there would be no pulsation of a shorter period. In spite of his wrong conjecture, such regular pulsations were named Eschenhagen waves in memory of the name of this pioneer researcher.

According to Holmberg (1953), another sort of *pc*'s of longer period, viz., 50 to 70 sec appear in the afternoon. The existence of such pulsations, however, has not yet been confirmed by other authors so clearly as in the case of Eschenhagen waves.

According to Terada (1917), regular pulsations of which period is shorter than 70 sec are apt to appear in the dayside and the maximum of the occurrence-frequency lies in the forenoon. On the other hand, regular pulsations of period longer than 90 sec appear usually in the nighttime and the maximum of the occurrence-frequency lies near the midnight. The slight secondary maximum appear around the noon. However, activity-curves of Angenheister (1954) show maximum in the dayside for each period intervals from several seconds to a few minutes.

(iii) Kato and Akasofu (1956) found a 27-day recurring tendency in the occurrence-frequency of *pc*'s in paralleity with the appearenc of solar UM regions. According to

Kato et al. (1956), pulsations of periods from 11 sec to 50 sec show clearly such a tendency.

The day-to-day variation of activity of pulsations of a longer period than 90 sec, is in good parralleity with that of the index A_k, which is believed to measure the disturbance grade of the polar storm. On the other hand, the maximum in the day-to-day variation of activity of pulsations of period shorter than 45 sec delays one day, compared to that of the index A_k (Fig. 6).

Through one year, *pt*'s appear most frequently in the equinoxes. *pg*'s are also apt to appear in the equinoqes, but the secondary maximum appears in summer (Sucksdorff, 1939). *pc*'s of period around 20 sec are most intensive in the equinoxes, but the time interval of occurrence in on day is the longest not in the equinoxes but in summer (Holmberg, 1953).

The period of the *pc* pulsation becomes shorter, when the magnetic disturbance is heavier (Kato and Watanabe, 1957; Obayashi, 1958).

(iV) It may be desirable to make vector-diagrams of perturbing force in pulsations. However, it should be noticed that the *E-W* component makes sometimes a different type of oscillation from that of the *N-S* component. (Terada, 1917).

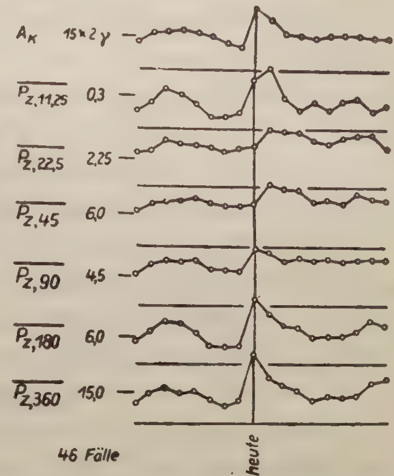

Fig. 6. Day-to-day variations of the geomagnetic index A_k and of the pulsational activities (after G. Angenheister).

The author also experienced such examples in the case of *pt* pulsation. On the other hand, the vertical component resembles very much the *N-S* component, of which amplitude is always greater than that of the former. The ratio of amplitude of the vertical component to that of the *N-S* component depends on the period concerned, that is, greater or smaller, when the period is longer or shorter (Fig. 7). The phase of the vertical component always lags to that of the *N-S* component (Terada, 1917). The phase-lag is usually greater than $\pi/4$ (Fig. 8), in contrast to the result of Duffus and Shand (1958); they found little phase-difference between both components.

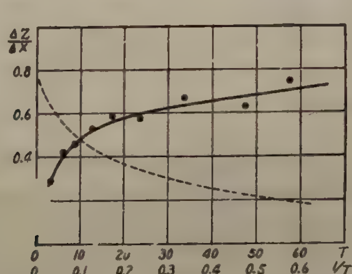

Fig. 7. Ratio of the amplitude of the vertical component to that of the *N-S*-component (after T. Terada).

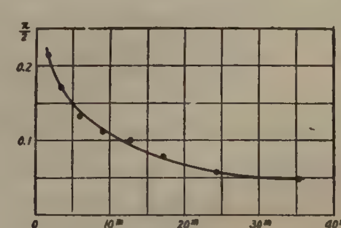

Fig. 8. Phase-lag of the vertical component to the *N-S*-component (after T. Terada).

The perturbing vector usually describes a figure, which resembles an ellipse. The direction of its long axis lies, in general, in the *N-E* quadrant during 01 to 16 h L.M.T. and in the *N-W* quadrant during 16 h to 01 h L.M.T. The rotation-sense of the perturbing vector is usually counter clockwise from 23 h to 06 h L.M.T. and from 12 h to 16 h L.M.T. During the other time intervals, the rotation-sense is usually clockwise. Shortly speaking, the rotation-sense shows a semi-diurnal variation (Terada, 1917). According to our observation (Kato et al. 1955), the axis of perturbing vector of *pt* lies in the *N-E* quadrant before midnight and in the *N-W* quadrant after midnight, in an agreement with Terada's result.

(V) It was detected by several authors (Angenheister, 1920; Kunetz, 1954; Kato et al., 1955) that *pt*'s occur over a considerably wide region on the earth's surface. Approximately speaking, *pt*'s occur on a world wide scale. Due to simultaneous observations at several stations distributed in Europa, Africa, U.S.A. and Venezuella, Kunetz (1954) suggested that the (intrinsic) occurrence-frequency of pulsations depends on G.M.T., but the intensity suffers the L.M.T. modulation. Thus, it gives a clue to solve a (superficial) contradiction that the (apparent) occurrence-frequency depends on L.M.T. irrespective of the G.M.T. dependence of the (intrinsic) occurrence-frequency.

Troitskaya (1953a, b, 1955) maintains that the maxima of the occurrence-frequencies of pulsations *pt*'s and *pc*'s fall respectively in the time-intervals from 18 h to 19 h G.M.T. and from 03 to 05 h G. M. T. It should be noticed, however, that 19 h G.M.T. corres-

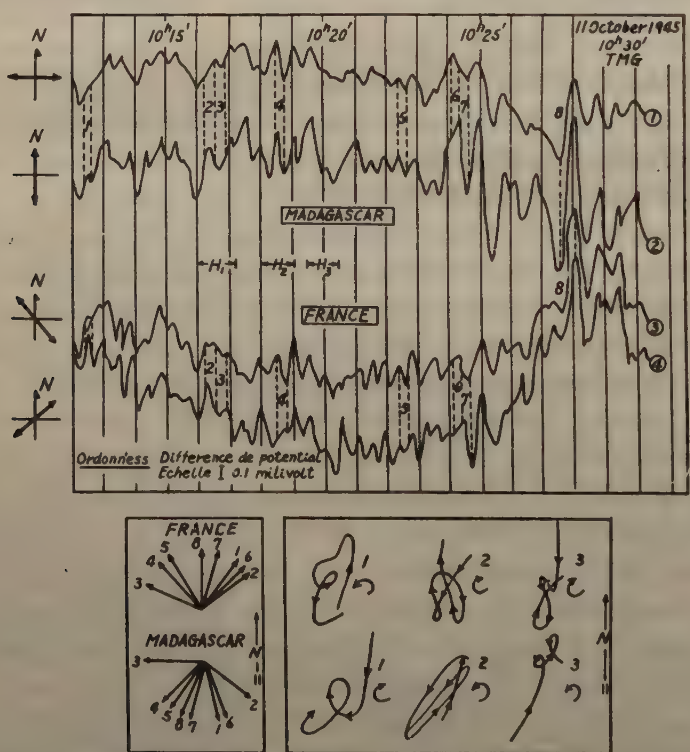

Fig. 9. Simultaneous observations *pc*'s in France and in Madagascar (after M. Schlumberger and G. Kunetz).

ponds nearly to the midnight at Alma Ata Observatory, the central station in Troitskaya's study, giving rise to L.M.T. enhancement of the amplitude of *pt*'s.

The latitude-depemdence of the amplitude of *pt* was studied by Veldkamp and Scholte (1955), who showed that the amplitude decreases more slowly than that of the accompanied bay as the colatitude of the observing station increases.

It is not yet established whether the *pc* pulsation would occur on a world wide scale or not. Kato and Okuda (1956) gave several examples showing that similar *pc*'s were recorded simultaneously in Ceylon and Japan. Schlumberger and Kunetz (1946) also gave a beautiful example showing that very similar *pc*'s in earth currents were observed simultaneously in France ahd Madagascar (Fig 9). In that case, the perturbing vectors rotated in reversed senses over and under the equator, and were directed symmetricallv about the equator. According to simultaneous observations at the two stations in east and west parts of Canada, correlation between pulsations obtained at the above two stations, is not always good, but rather complicated.

(vi) Effect of the eclipse to the geomagnetic pulsation was searched by several authors without any definite conclusions. Astbury (1952), and Kato and Okuda (1956) repoted the weakening of the intensity of pulsations in the eclipse-zone, but the intensification of the amplitude was detected by Kunetz (1954).

3. Giant Pulsations

The giant pulsation, *pg*, was first discovered by Rolf (1931), after whom Harang (1932) and Sucksdorg (1939) studied it in detail. According to Harang (1932), most of *pg*'s appear during the time interval from 22 h to 08 h L.M.T.

According to Sucksdorff (1939), *pg*'s are classified into two types, A and B. The A type *pg* appears as a train of regular pulsations, of which envelope resembles a shuttle very much and occurs most frequently around 03 h L.M.T. On the other hand, B type *pg*'s show nearly sinusoidal oscillations, but the from of its envelope is rather irregular. The maximum of the coourrence-frequency of B type *pg*'s lies around 10 h L.M.T. Canadian researchers picked up *pg*'s larger than 3γ at Meannook (61.8°*N*) and classified them into A and B typs according to Sucksdorff's criterion. In the contrary of Sucksdorff's study (1939), B type *pg*'s are apt to occur around the midnight, and A type ones before the noon. The local hour of the maximum of the occurrence-frequency of B type *pg*'s do not move year-to-year. On the other hand, that of A type *pg*'s comes nearer to the noon, on a year of heavier activity of sunspot (Whitham and Loomer, 1958).

The period of *pg* lies, in general, between 1 and 2 miniutes and the occurrence-frequency of periods suggests existence of a nearly harmonic spectrum of eigenperiods (Kato and Watanabe, 1954, 1956). However, the data may be too scanty to draw such a result.

It is reported that *pg*'s appear as regular pulsations only in the extent considerably less than 2000 to 3000 kms (Whitham and Loomer, 1958).

4. Vibrations

At a station in the aurroral zone, very rapid pulsations were observed, of which period is shorter than 1 sec and of which amplitude amounts to some tens of gammas. Such rapid pulsations are apt to appear in the equinoxes. The maximum of the diurnal curve of the occurrence-frequency lies between 08 h and 10 h L.M.T., coincidental to that of *pc*'s in the middle latitude region. The slight secondary maximum appears between 20 h and 22 h L.M.T., coincidental with the maximum of the occurrence-frequency of *pt*'s. This type of pulsations are apt to appear repeatedly with 24 hr intervals. (Harang, 1936).

Suckscorff (1936) discovered rapid pulsations, of which period is 2 to 3 sec. Such pulsations occur, continuously for many hours, sometimes for one day or more, and their envelope shows very often a train of shuttles. Thus, this type of pulsations often appears like a necklace of pearls. They are apt to appear in the daytime. The maxi mum of the diurnal curve of the occurrence-frequency lies before 12 h L.M.T. in January, and moves towards the evning according to the seasons. In June and July, it lies between 16 h and 17 h L.M.T., and after them, it returns again to the hours before the noon.

Chernosky et al. (1954) also found rapid pulsations, of which period is 2 to 7 sec. But, they reported that such rapid pulsations are apt to appear in the night time. Troitskaya (1953a, 1955) detected pulsations of period 2 to 3 sec, which very often accompanied by a bay disturbance. According to her, this type of pulsation corresponds

Fig. 10. Geomagnetic vibrations in earth currents accompanied by bay disturbances (after V.A. Troitskaya).

to the bay disturbance far better than the *pt* type of pulsations (Fig. 10).

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8. Particles of Aurorae and Geomagnetic Pulsations

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Abstract

It is shown that the geomanetic pulsation is caused by hydromagnetic oscillation of the exosphere excited by solar charged corpuscles impinging on the earth as predicted by Störmer. Pc-type pulsations are excited by auroral particles impinging on the 09 h impact-zone, of which latitude is higher than the usual auroral zone and which gives rise to a second auroral zone as suggested by Nikolsky. Pt-tpye pulsations are excited by particles impinging on the 21 h zone, corresponding to the usual auroral zone. The L.M.T. dependence of the occurrence-frequency of geomagnetic pulsations is well explained, assuming that the intensity of geomagnetic pulsations at a station will be lesser as it is more distant from the impact-zone. On the other hand, the G.M.T. control in the occurrence-frequency, as suggested by Troitskaya, is to be expected due to an inclination of the geomagnetic axis to the axis of rotation of the earth.

1. Introduction

It was suggested that the hydromagnetic oscillation of the earth's outer atmosphere (exosphere) would give rise to the fluctuation of the geomagnetic field, which is named "geomagnetic pulsation" (Dungey, 1954; Kato and Akasofu, 1956; Kato and Watanabe, 1956, 1957a). However, it is not yet known what excite the exospheric oscillation. Our suggestion to this point is as follows: positive charged particles, presumably protons, flying from the sun would impinge on the earth as predicted by Störmer (1955) and would collide with the denser matter in lower part of the exosphere to cause a hydromagnetic oscillation of the exosphere. That is, the ultimate origin of the geomagnetic pulsation may be said to be particles of auroare in a wider meaning. Evidence will be presented that both L.M.T. and G.M.T. controls in the occurrence-frequency of the geomagnetic pulsation may be explained well by our picture.

Since spiral structure of the auroral belt was suggested by a few authors* (Meek, 1955; Hope, 1956; Nikolsky, 1956, 1957 a, b, c), Störmer's theory is reviving, which is, at the present time, the unique one to predict a spiral structure. From the standpoint of Störmer's theory, Nikolsky (1957 c) suggested the existence of a second auroral zone, of which latitude is higher than that of the usual auroral zone and detected it by

* Recently, Mr. Hakura detected the spiral structure of the auroral belt, using f_{min}'s on ionograms during the main phase of a severe geomagnetic storm (Lecture at a meetng of the Ionosphere Research Committee in Japan, December, 1958).

magnetic survey in the arctic region.

We shall show that there are two types of geomagnetic pulsation corresponding to two groups of auroral particles imping on the two auroral zones respectively and show the daily variation of the occurrence-frequency of each type of geomagnetic pulsation which may be well explained by Störmer's theory. Relationship between geomagnetic pulsations and aurorae will give us a powerful means for study on electrodynamical behaviour of auroral particles.

2. Daily Variation of the Occurrence-Frequency of the Geomagnetic Pulsation

It may be pertinent to give comments on observatonl facts concerning geomagnetic pulsatiions (Kato and Watanabe, 1957b).

Geomagnetic pulsations are classified into three types:

pc....A series of pulsations lasting for many hours. The period lies, in general, between 10 and 60 sec and the amplitude amounts to the order of $1/10\,\gamma$. The intensity depends on L.M.T. and the maximum of the occurrence-frequency lies during the morning time (Fig. 3).

pt....A series of pulsations of limited duration lasting usually ten minutes or more, often preced or accompany a bay disturbance. A typical *pt* shows a series of damped oscillations. The damping time is of the order of 10^2 sec. The maximum of the occurrence-frequency falls before midnight (Fig. 3).

Pulsations, which one observes usually in the middle or low latitude regions, are of these two types. Besides these, there is another type of pulsations named the giant pulsation (*pg*).

pg....A series of pulsations of large amplitude that appear in the auroral zone only. The amplitude amounts to several to a few tens of gammas. The durations is of the order of one hour or more. The period is longer than that of *pc*'s; 40 sec to several minutes. Sucksdorff (1939) classified *pg*'s into two types, A and B. The maximum of the occurrence-frequency of A type *pg*'s falls around 03 h L.M.T., and that of B type ones around 10 h L.M.T.

In the following discussions, we shall concern ourselves with *pc*'s and *pt*'s only. At first sight, the occurrence-frequency of each type of geomagnetic pulsations seems to depend on L.M.T. However, Troitskaya (1953) suggested by simultaneous observations at several observatories widely distributed in the USSR that the occurrence-frequencies of *pc*'s and *pt*'s depend not on L.M.T. but on G.M.T. According to her observations, the intrinsic number of occurrence-frequency depends on G.M.T., though the intensity of pulsation may vary dependent on L.M.T. Our theoretical considerations will show that the occurrence-frequency depends not only on L.M.T. but also on G.M.T. However, it appears that the G.M.T. control is so weak as to be masked by the L.M.T. control and thus, the occurrence-frequency in a single station, apparently, depends on L.M.T.

3. Some Results from Störmer's Theory

Here, we summarize some results of Störmer's theory, which will help us for the

following discussions.

(1) Nikolsky's Remark There are four regions on the spiral belt of aurorae, on which solar charged corpuscles impinge more densely. In other words, there are four impact zones of auroral particles. Fig. 2 shows the locus of points, where charged corpuscles of a constant stiffness can fly into from the sun. It is clearly seen that there are four impact-zones, A,B,C and D. Birkeland's model experiment shows that regions A and C are illuminated strongly, in particular, by impinging particles. The latitude

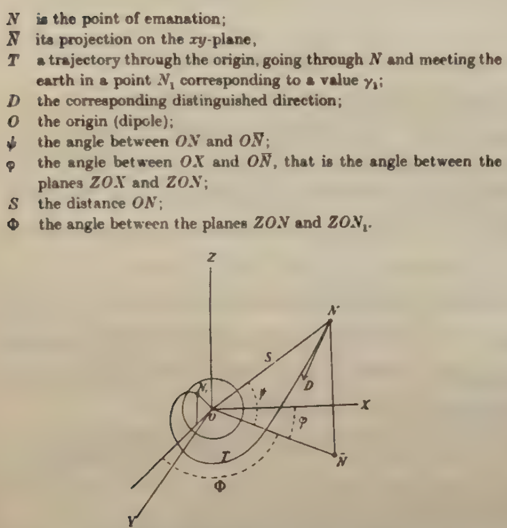


Fig. 1. Coordinates used for calculation of Störmer orbits (after Störmer).

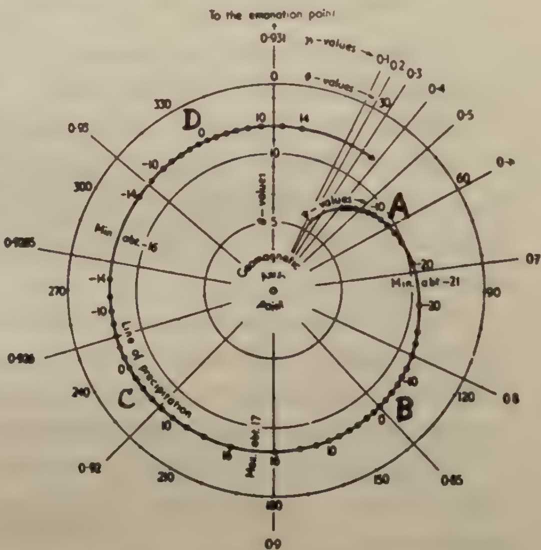


Fig. 2. Locus of points of precipitation of positive charged corpuscles with a constant stiffness 10^5 (corresponding to the velocity of $9.6 \cdot 10^8$ cm/sec in the case of protons) (after Störmer).

of the zone A is higher than others. Nikolsky's second auroral zone is due to corpuscles impinging on the zone A.

(2) Figs. 1 and 2 shows that corpuscles impinging on the regions A and C come from the positions of the sun 10° high and low relative to the geomagnetic equator. It suggests us that charged corpuscles will impinge on the region A (or C) more densely, as the lower (or higher) is the "coming in" direction of charged corpuscles relative to the geomagnetic equator.

4. Theoretical Interpretation of the Daily Variation of the Occurrence-Frequency of the Geomagnetic Pulsation

It may be noticed that the L.M.T.'s of the maximum of the occurrence-frequencies of geomagnetic pulsations, *pc*'s and *pt*'s, correspond to the longitudes of the impact-zones, A and C (Fig 3). It suggests that geomagnetic pulsations *pc*'s and *pt*'s would

* Attention to a parameter ψ in Fig. 2, which means an elevation of the "coming in" direction of a particle reilative to the geomagnetic to the geomagnetic equator (Fig. 1).

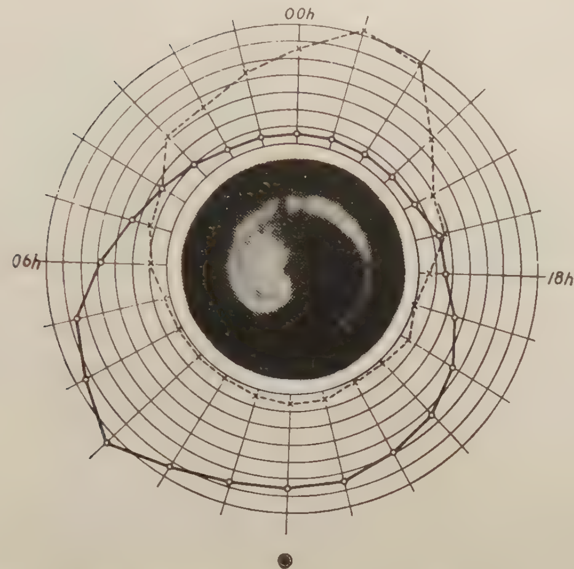


Fig. 3. The relationship between positive charged corpuscles impinging on the auroral zone and the diurnal variations of the geomagnetic pulsations, pc's and pt's. The solid line refers to the occurrence-frequency of pc's and the dotted line to pt's. The pattern of precipitation of auroral particles was obtained with a negative film turned over which reproduces the result of Birkeland's experiment by electrons.

be caused by charged corpuscles impinging on the zones, A and C respectively. We shall try to interpret it, assuming that positive charged corpuscles, presumably protons, would cause an hydromagnetic oscillation, colliding with the denser matter in the lower exosphere. There is no observational fact, at present, to decide whether the solar corpuscular stream consists of the same number of positive charged corpusclles (presumably protons) and of negative charged ones (electrons) or not. However, electrons, if any, could make little contribution to the exospheric oscillation because of their slight masses.

The hydromagnetic oscillation of the exosphere in the earth's main magnetic field is so difficult to be solved anayltically that only an axisymmetric case is treated approximately. In that case, exospheric oscillations are classified into two types; poloidal and toroidal. In the latter type, the exospheric matter constrained within each surface of revolution of magnetic lines of force makes torsional oscillateion each independently of the other. The eigenperiod depends on the latitude very sensitively, where the magnetic lines of force cut the earth's surface. The magnetic and velocity vectors are directed to east-west. On the other hand, in the poloidal oscillation, the magnetic and velocity vectors oscillate in each meridian plane simultaneously in the same period.

Roughly speaking, solar charged corpuscles impiging on the lower exosphere would cause two types of hydromagnetic oscillation of the exosphere. The toroidal oscillation will be limited to the latitude, on which auroral particles could impinge. It suggests that

the toroidal oscillation represent roughly the giant pulsation, *pg*, which appears in the auroral region only. On the other hand, the hydromagnetic oscillation excited by auroral particles will appear in the lower latitude regions too, through the poloidal type of oscillation. Thus, the poloidal would roughly represent *pc*'s and *pt*'s.

In a meridian plane involling an impact-zone, on which auroral particles impinge, the intensity of geomagnetic pulsations, *pc*'s and *pt*'s, will decrease, as the distance of an observing station from the impact-zone increase. In an axisymmetric case, the intensity will be constant on a latitude circle. In real cases, however, the intensity will decrease as the longitudinal distance of the station from the impact-zone increases. Let λ_0, ϕ_0 and λ, ϕ be the geomagnetic latitudes and longitudes of the impact-zone and the observing station respectively. Then, the amplitude A of the geomagnetic pulsation at the sation will be a decreasing function of $|\lambda-\lambda_0|$ and $|\phi-\phi_0|$:

$$A=A(|\lambda-\lambda_0|, |\phi-\phi_0|)$$

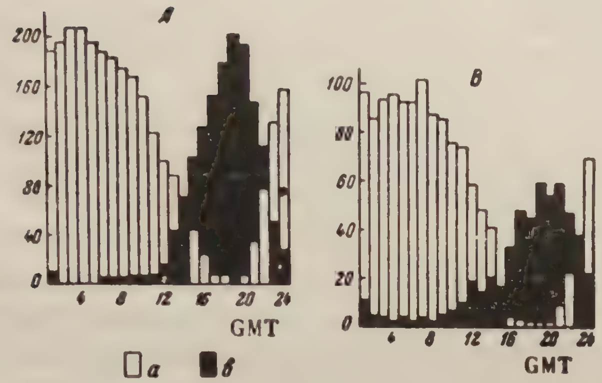
Therefore, the intensity of the geomagnetic pulsation, *pc* (or *pt*) will be the greatest, when the L.M.T. of the station will coinicide with the longitude of the impact-zone A (or C).

The maximum of the daily curve of the occurrence-frequency of *pc*'s is flatter than that of *pt*'s. It may be due to the higher latitude of the zone A compared with the zone C.

Next, we shall try to explain the G.M.T. control in the occurrence-frequency of geomagnetic pulsations, *pc*'s and *pt*'s. The geomagnetic axis is inclined to the rotation-axis of the earth, and thus the position of the sun relative to the geomagnetic equator varies according to G. M. T. At equinoxes, when geomagnetic pulsations appear most frequently, the solar position relative to the gemagnetic equator is lowest ($\psi=-11.5°$) or highest ($\psi=11.5°$) on the midnight-or noon-meridian passage of the geomagnetic N pole. The remark (2) in the section 3 tells us that, in the former case, solar charged corpuscles are apt to impinge on the region A, and in the latter case, on the region C. Because the geomagnetic N pole is situated at 69° W, it crosses the midnight-or noon-meridian at 4.6 h or 16.6 h G. M. T.'s. Therefore, the occurrence-frequency of geomagnetic pulsations must be corrected by multiplying a factor. $C(|\tau-\tau_0|)$, a decreasing function of its argument, where τ is the G.M.T. and $\tau_0=4.6$ h and 16.6 h G. M. T.'s for *pc*'s and *pt*'s respectively:

$$F=C(|\tau-\tau_0|)\times A(|\lambda-\lambda_0|, |\phi-\phi_0|)$$

Observations in a single station show a clear L. M. T. dependence of the occurrence-frequency of the geomagnetic pulsations. The L. M. T. contorl may be more effective than the G. M.T. contorl. Troitrkaya's attempt is, in our opinion, to clarify the G.M.T. control, elimineting the L.M.T. masking effect by simultaneous observation at stations widely distributed. The result is that the maximum of the occurrence-frequency of *pt*'s and the minimum of *pc*'s lie between 19 h and 20 h G. M. T. On the other hand, it appears that the maximum of *pc*'s and minimum of *pt*'s lie between 7 h and 8 h G.M.T.



A. Distribution of Type I and Type II oscillation:
  a. Type I oscillation according to earth-current traces at recording-speed 1 mm/sec at Alma Ata and Garm, for December 1951 to August 1952.
  b. Type II oscillatory bursts, accrding to earth current recordings in Central Asia for 1951–1952.

B. Distribution of Type I and Type II oscillations for vertical component of magnetic field, as recorded with A. G. Kalashnikov's fluxmeter apparatus for six months of 1951.

Fig. 4. Diurnal variations of the occurrence frequencies of pc's (Type I) and of pt's (Type II, shadowed) (after Troitskaya).

We notic nearly two or three hours discrepancy between the theoretical prediction and the observation. This discrepancy may be due to distortion of the geomagnetic field from that of the centered dipole. In order to explain the westwards shift of the cosmic ray equator to the geomagnetic equator of the centered dipole, Simpson et al. (1956) suggested a westwards rotation of the geomagnetic axis by 40° to 45°, which may also annul the discrepancy in our case.

Due to symmetry, solar charged corpuscles are apt to impinge on the zones A and C in the southern polar region, when the geomagnetic S pole crosses the midnight-or noon-meridian; at 19–20 h and 7–8 h G.M.T.'s. Therefore, we shall have similar curves of occurrence-frequencies of *pt*'s and *pt*'s with a phase-shift of half a day, if we otain the G.M.T. curves of occurrence-frequencies near the southern auroral region. In the equatorial region, we shall have semidiurnal curves.

Recently, the above idea of Simpson et al. was criticized by Rothwell (1957), who maintains that the anomalous behaviour of cosmic ray praticles may be determined greatly by the anomalies in the geomagnetic field within 1,000 km from the earth's surface. If so, auroral particles may also be influenced by the anomalies in the neighbourhood of the earth's surface and, thus, Troitskaya's suggestion may be justified that the G. M. T. of the maximum of the occurrence-frequency may be related to the noon-meridian passage of the true magnetic north pole. Observations in the neighbourhood of the southern auroral region will give us the necessary informations to decide

* A pt accompanying a bay disturbance is named bp. If the registered curve of a bay moves steeply in a magnetogram, it is noted with bps.

whether Simpson's idea may be justified or not, because the G.M.T. of the noon meridian passage of the true magnetic *S* pole, is near 10 h, distant from that of the *N* pole. Detailed observations of the occurrence frequency of the geomagnetic pulsation may be desirable, which will give us informations not only to the problem of precipitation of auroral particles, but also to studies on the distortion of the geomagnetic field.

5. Some Remarks

(1) As stated before, *pt*'s are in close connection with bay disturbances. It is a well known fact that a train of pulsations, *pt*, appears only from the initial stage of a bay disturbance till the maximum phase; in the diminishing phase, *pt*'s do not appear (Kato and Watanabe, 1957b).

This fact seems to give a support for the dynamo theory of the bay disturbance (Fukushima, 1953), which maintains that the ionospheric current responsible for the bay disturbance, would be caused by the dynamo-action amplified in the polar region due to the ionospheric conductivity increased by impinging auaroral particles. The above-mentioned fact suggests that auroral particles impinge on the earth till the maximum phase of the bay disturbance and, after that, the bay disturbance will decay due to the decrement of the ionospheric conductivity by recombinations of electrons or by other effects (i.e. diffusion).

When the recombination coefficient is taken to be of the order of $10^{-8} \sim 10^{-9}$ sec^{-1} cm^{3}, the time constant of decay of the bay disturbance amounts to $10^{3} \sim 10^{4}$ sec, which is compatible with observation.

(2) It should be noticed that *pc*'s last continously and *pt*'s intermittently. This fact suggests that there are two kinds of corpuscular streams: One is a continuous stream of lower energy particles, which would impinge on the zone *A*. The other consists of higher energy particles, which fly into the earth intermittently. The above comment is purely speculative. However, it may be noticed that aurorae in the high latitude region are constant and diffusing. (Bennett, 1958). A theoretical study may be desirable, how the pattern of precipitation of charged corpuscles would vary according to the energy of particles concerned.

(3) Auroral particles impinging on the zones, *B* and *D*, would also have contributions to the occurrence-frequecy of the geomagnetic pulsation. A second maximum is noticeable in the daily curve of the occurrence-frequency of *pt*'s (Yanagihara, 1958). It may be due to particles impinging on the zone *B*. We notice also a second flat maximum in the daily curve of *pc*'s in the afternoon side (Fig. 3), which may be due to D-particles. *P c*'s are apt to appear in the afteanoon time during the summer (Saitô, 1955). Auroral particles would be apt to impinge on the zone *D*, when the "coming in" direction is higher as in the summer time.

6. Implications to the Theories of the Geomagnetic Storm

Störmer's theory has been reproached by the reason that the velocity of charged corpuscles, $\sim 10^{8}$cm/sec, conjectured from the delay of the beginning of the geomagnetic

storm to the relating solar phenomenon, is lower one order than that necessary to precipitate the usual suroral zone. However, there has been no evidence showing that the solar corpuscular stream does not contain higher speed ($\sim 10^{9}$ cm/sec) particles. On the other hand, the earth's magnetic field would not be of dipole as assumed in Störmer's theory. It must be noticed that there is an experiment showing that the ring current field, which may be always exstent to a certain extent, helps corpuscles to impinge on the lower latitude region (Brüche, 1930).

It is doubtful, from the present knowledge on the inter-planetary magnetic field, that the earth's dipole magnetic field survives the neighbourhood of the sun as assumed by Störmer. Charged corpuscles, however, will be influenced by the earth's magnetic field more severely, as they are nearer from the earth. Störmer's assumption may be justified as a mathematical approximation.

Another serious objection is due to Shuster (1911), who maintains that charged corpuscles of single sign will diverge by Coulomb's repulsive force during their travel from the sun to the earth, and that the corpusclar stream should be electrically neutral, being made of equal number of positive and negative charged corpuscles. Störmer's theory, however, does not necessarily demand that the corpuscular stream should be made of charged corpuscles of single sign, but assumes that the effects of the electric and magnetic fields induced within the stream, may be neglected before that of the earth's magnetic field.

It is needless to say that the motion of a charged particle, say a proton, can by no means be described as that of a single particle in the earth's main magnetic field, but should be described by the following equation, including the electric and magnetic field $\boldsymbol{E}$ and $\boldsymbol{h}$, which would be produced by the mutual interaction between the corpscular stream and the eath's main magnetic field $\boldsymbol{H}$, or by other mutual interactions possible between protons and electrons in the corpuscular stream itself:

$$m_p \frac{d\boldsymbol{v}_p}{dt} = e\left[\boldsymbol{E} + \frac{1}{c}\boldsymbol{v}_p \wedge (\boldsymbol{H}+\boldsymbol{h})\right]$$

The effect due to collisions may be negligible because of the smaller velocities of thermal motions compared with that of the mean flow.

Various theories of geomagnetic storms and aurorae have been developed on the basis of various interpretations about the electric and magnetic fields $\boldsymbol{E}$ and $\boldsymbol{h}$. It must be noticed that the essential point of Störmer's theory does not censist in assuming that the sign of charged corpuscles would be unique, but that the induced electromagndtic fields $\boldsymbol{E}$ and $\boldsymbol{h}$ were not be neglected. Störmer's theory may be said to be of a "single" particle in this sense, too.

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* Alfvén's theory (1950) is also of "single" particle so long as he constructed his theory on the basis of the motion of one particle in the electric and magnetic fields $\boldsymbol{E}$ and $\boldsymbol{h}$ as well as the earth's main magnetic field, which were given independently from the electrodynamical behavionr of the corpuscular stream. Bennet and Hulbert (1954) consider that the magnetic field $\boldsymbol{h}$ due to the differential motion between protons and electrons would give rise to a pinch effect to prevent the divergence of charged corpuscles of one sign.

however, does not necessarily mean that the

and magnetic fields induced within the stream, may be neglected below that of the
earth's magnetic field

Chapman and Ferraro (1931) treats the corpuscular stream as a mass of conductive matter, and thinks that the electromagnetic fields induced within the stream in itself, would cancel the motional-induction force $1/c\ \boldsymbol{v}_p \wedge \boldsymbol{H}$ consideradly. The essential point of some author's opinions (Martyn, 1951; Nagata, 1954) consists in idealizing Chapman and Ferraro's idea: The conductivity of the corpuscular stream is so good that the electromagnetic fields induced within the stream would completely cancel the earth's main magnetic field. That is, the R.H.S. of the above equation may be set into zero and charged corpuscles neither retarded nor accelerated so long as within the corpuscular stream, and further, be reflected back only at the frontal surface of the corpuscular stream. From this point, the ideas are justified that the earth's main magnetic field acts as a bumper for the corpuscular stream and that the balance should be held between the pressure of the earth's magnetic field and the kinetic pressure of the corpuscular stream.

So long as it is conerned with the mutual interaction between the corpuscular srteam and the earth's main magnetic field, we recognize that Störmer's theory and that of Chapman-Ferraro are two idalized extremes. Both theories were based on their own assumptions. In order that Chapman-Ferraro's theory may be justified, the following two points checked:

(1) The charged corpuscles advance to the earth as a stream with a wide frontal surface. If charged corpuscles approach the earth in small blocks, Chapman-Ferraro's theory would no longer hold true. The condition whether the Chapman-Ferraro's effective or not depends on the structure of the corpuscular stream itself, which cannot be determined by theoretically only.

(2) Even if the condition (1) would be fulfilled, it must be proved, not from the standpoint of electrodynamics of macroscpic substances but from of plasmas, and that the induction within the stream effective enough to cancel the earth's main magnetic field.

Conclusively, we cannot yet decide which is better, Störmer's theory or Chapman-Ferraro's one. Both theories are not completeley justificd in the sense that they do not succeed in explaining all the phanomena relating to geomagnetic storms and aurorae. It may be conjectured that both Störmer's and Chapman-Ferraro's theories would become effective according to surrounding circumstances. At least, it may be anticipated that a progress will be made in a direction to synthesize both theories in a consistent from.

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9. Hydromagnetic Oscillation of the Outer Ionosphere and Geomagnetic Pulsation*

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Abstract

A suggestion is given that resonance is possible to occur in the hydromagnetic oscillation of the lower part of the exosphere to give rise to the geomagnetic pulsation. The hydromagnetic oscillation of the lower exophere giving rise to the pt type pulsation may be excited by solar charged corpuscles impinging on the auroral zone. The pc type pulsation may be caused by corpuscles impinging on the second auroral zone, of which latitude is higher than that of the usual auroral zone. Therefore, corpuscles impinging on the second auroral zone would give rise to a higher order mode of oscillation due to higher latitude of a loop of oscillation, resulting in the shorter period of the pc type pulsation compared to that of the pt type pulsation. Some observational facts lead us to a speculation that the pc type pulsation be caused by a continuous flow of solar charged corpuscles, and its velocity may be of the order of 10^8 cm/sec, and that the pt type pulsation, due to corpuscles, accelerated intermittently by magnetic clouds in a mean flow of solar corpuscles.

1. Introduction

It is suggested by Dungey (1954 b) that the geomagnetic pulsation, fluctuation of the intensity of the earth's magnetic field, of which amplitude is of the order of 0.1 γ or more, and period ranges from 0.1 sec to several minutes, would be caused by hydromagnetic oscillation of the earth's outer atmoshpere in the earth's main magnetic field. Due to the relative motion between the earth and the solar corpuscular stream (Capman and Ferraro, 1931 a, b; 1932 a, b) or between the earth and the interplanetary matter (Dungey, 1954 b), the earth's magnetic field would be confined into the region, and its radius would cover several to ten earth's radii. The interplanetary gas trapped into such a region is, namely, the outer atmosphere or the exosphere, of which mean density is conjectured to be several hundreds electrons and protons per cubic centimeter from Storey's studies on whistling atmospherics (Storey, 1953).

Dungey (1954 b) established fundamental equations for the exospheric oscillation. It is so difficult to get a general solution that he treated the axisymmetric case, where two sets of field quantities are governed, by two different equations of oscillation; torsional and polidal. In the former, the exospheric matter, constrained within each

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surface of revolution of magnetic lines of force, makes torsional oscillations independently of the other. The eigenperiod depends on the latitude very sensitively, where the magnetic line of force cuts the earth's surface. The magnetic and velocity vectors are directed to east-west. On the other hand, in the poloidal oscillation, the magnetic and velocity vectors oscillate in each meridian plane simultaneously with the same period.

It seems natural, at the first step, that one attempted to regard the poloidal oscillation to correspond to a sort of gemagnetic pulsations, which appear extended largely latitudinally (Dungey, 1954 b), although the axisymmetric treament discards the diurnal behaviour of the geomagnetic pulsation.

In the middle latitude region, we usually encounter two types of geomagnetic pulsations; pc's and pt's, which seem to be observed simulaneously at many stations distributed over a considerably wide region of the world.

pc ... A series of pulsations lasting for many hours. The period lies, in general, between 10 and 60 sec and the amplitude amounts to the order of $1/10\ \gamma$. The intensity depends on L. M. T. and the maximum of the occurrence-frequency lies in a morning hour.

pt ... A series of pulsations of limited duration lasting usally ten minutes or more, often preceding or accompaying a bay disturbance. A typical pt appears as a series of damped oscillations. The mean period ranges from a few tens seconds to several minutes; longer than that of pc's. The damping time is of the order of 10^2 sec. The amplitude amounts to the order of $0.5\ \gamma$ or more; larger than that of pc's. The maximum of the ocourrence-frequency falls before midnight.

Putting briefly, the principal points to be concidered theoretically are as follow:

(1) There are two types of geomagnetic pulsations.

(2) The occurrence-frequencies of pc's and pt's show respective diurnal variations. Besides, there are G. M. T. controls in the occurrence-frequencies (Kato and Watanabe, 1958).

(3) Pc's last continuously. On the other hand, pt's appear intermittly.

(4) Steady oscillations of pc's and damped oscillations of pt's suggest that geomagnetic pulsation would be caused by any resonance system near the earth. Does such a resonance system exist? If it does, why is the period of pc's shorter than that of pt's?

Suggestions about the points from (1) to (3) were already published in our paper (Kato ahd Watanabe, 1958): Solar charged corpuscles of positive sign, presumably protons, impinge on the earth as predicted by Störmer (1955) and collide with the denser matter in the lower exosphere, which gives rise to the geomagnetic pulsation as suggested by Dungey (1954 b). The two types of geomagnetic pulsations, pc's and pt's, correspond to the two groups of solar corpuscles impinging on the two impact-zones expected from Störmer's theory. An impact-zone in the night side, around 21 h L. M. T. and corresponding to pt's, is situated at the lower latitude than the other impact-zone in the forenoon side, around 09 h L. M. T., which corresponds to pc's and gives rise to the second auroral zone as detected by Nicolsky (1957). Our picture explains well not only

the L. M. T. variations but also the G. M. T. controls of the occurrence-frequencies of respective types, if we take into account the G. M. T. variation of the orientation of the geomagnetic axis relative to the sun due to the inclination of the geomagnetic axis to the earth's rotation-axis.

As for the point (4), essential for the problem of the geomagnetic pulsation, Dungey (1954 b) estimates that the fundamental period is of the order of 1/2 to 1 hours, assuming that the radius of the exosphere is of the ordere of ten earth's radii and the density is of the order of 600 protons/cm^3. The period is, however, far longer than that of pc's and pt's. According to our estimation (Kato and Watanabe, 1957), the period may be compatible with observation, if we take the radius of the exosphere smaller, viz., 3~6 earth's radii. Another suggestion, is, of course, tentative to identify pc's and pt's with higher order modes of oscillation (Kato and Watanabe, 1957).

In these suggestions, however, there still remain ambiguous points on the geometry of the exoshere and distribution of the magnetic field as well as that of the exospheric matter. It seems, therefore, not meaningless that one would try to derive the compatible period on the base of a model founded on definite data on the physical state in the exosphere.

The above-stated picture on the agent of the geomagnetic pulsation suggests that the energy exciting exospheric oscillations would be brought into the lower part of the exosphere. On the other hand, we have now data on the distribution of matter in the lower exosphere obtained by the artificial satelite (Al'pert, 1958). Thus, we are in position to treat fundamental equations of the hydromagnetic oscillation in the lower exosphere with more knowledge.

2. Hydromagnetic Oscillation in the Lower Exosphere

The fundamental equations established by Dungey (1954 b) are as follows:

$$\left.\begin{aligned}
&\left[4\pi\rho H^{-2}\frac{\partial^2}{\partial t^2}-r^{-2}\sin\theta\frac{\partial}{\partial\theta}\sin^{-1}\theta\frac{\partial}{\partial\theta}-\frac{\partial^2}{\partial r^2}\right](r\sin\theta E_\phi)\\
&\qquad=c^{-1}\sin\theta\left(H_r\frac{\partial}{\partial\theta}-H_\theta r\frac{\partial}{\partial r}\right)\left((r\sin\theta)^{-1}\frac{\partial u_\phi}{\partial\phi}\right),\\
&\left[4\pi\rho\frac{\partial^2}{\partial t^2}-(r\sin\theta)^{-2}\left((\boldsymbol{H}\nabla)(r\sin\theta)^2(\boldsymbol{H}\nabla)+H^2\frac{\partial^2}{\partial\phi^2}\right)\right]\left(\frac{u_\phi}{r\sin\theta}\right)\\
&\qquad=c(r\sin\theta)^{-3}\left(H_r r^{-1}\frac{\partial}{\partial\theta}-H_\theta\frac{\partial}{\partial r}\right)\left(r\sin\theta\frac{\partial E_\phi}{\partial p}\right)
\end{aligned}\right\}\quad(1)$$

Here, we use the system of the spherical polar coordinates, r, θ and ϕ. r represents the distance of a representative point from the earth's center, where the earth's magnetic dipole is situated in the sense of negative direction of the polar axis ($\theta=\pi$). These equations were obtained on assumption that the exospheric matter are incompressible, but the density may not be uniform in the places. For an axisymmetric case, the above equations are reduced to

$$\left.\begin{aligned}\left[4\pi\rho H^{-2}\frac{\partial^2}{\partial t^2}-r^{-2}\sin\theta\frac{\partial}{\partial\theta}\sin^{-1}\theta\frac{\partial}{\partial\theta}-\frac{\partial^2}{\partial r^2}\right](r\sin\theta E_\phi)=0\,,\\ \left[4\pi\rho\frac{\partial^2}{\partial t^2}-(r\sin\theta)^{-2}(\boldsymbol{H}\nabla)(r\sin\theta)^2(\boldsymbol{H}\nabla)\right]\left(\frac{u_\phi}{r\sin\theta}\right)=0\,.\end{aligned}\right\}\quad(2)$$

The former equation, called the equation of poloidal oscillation, determines the r and θ components of the velocity and the magnetic vectors, and the ϕ component of the electric field. The latter equation, that is for the torsional oscillation, governs the ϕ component of the velocity and magnetic vectors, and the r and θ components of the electric field.

The equation of poloidal oscillation is written as follows, if we assume that the field quantities depend on the time through the factor $e^{i\omega t}$:

$$\left(\frac{\partial^2}{\partial R^2}+\frac{1-\mu^2}{R^2}\frac{\partial^2}{\partial\mu^2}+\frac{4\pi\rho a^2\omega^2}{H^2}\right)(R\sin\theta E_\phi)=0 \qquad (3)$$

where R is the radial distance measured in units of the earth's radius, that is, $R=r/a$ and $\mu=\cos\theta$.

The last term of this equation depends on the variables R and θ, even if we assume that the density is distributed symmetrically about the earth's center. The Alfvén velocity $H/\sqrt{(4\pi\rho)}$ varies only in the ratio 2 : 1 from the pole to the equator in a constant height-level, but varies very rapidly against the height from the ionosphere to the lower exoshere. It was first detected by Dessler (1958 a, b), who suggested its significance for the rapid variations in the earth's magnetic field. Fig. 1 b shows the variation of the Alfvén velocity against the height-variation of the plasma-density conjectured from an observation by an artificial satelite (Al'pert, 1958). The field intensity at the earth's

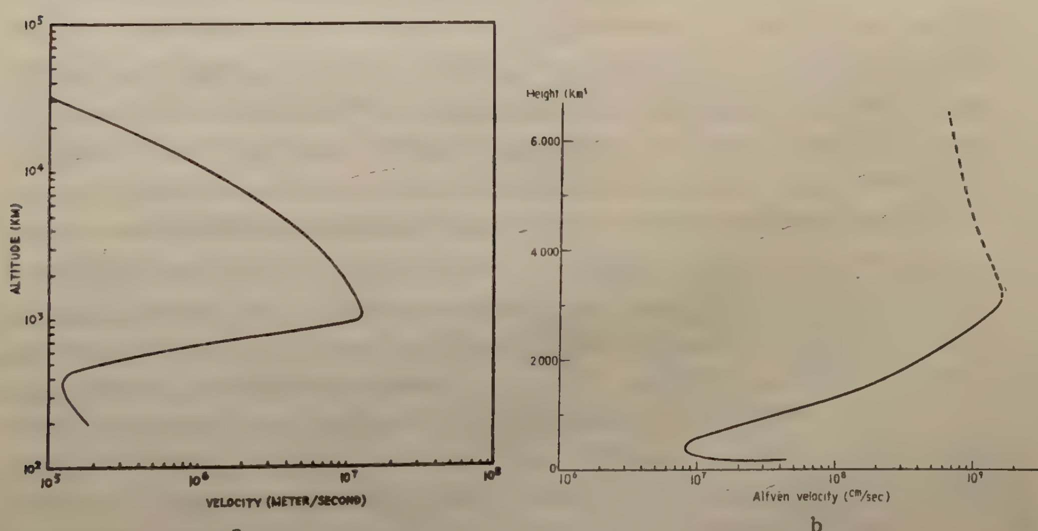
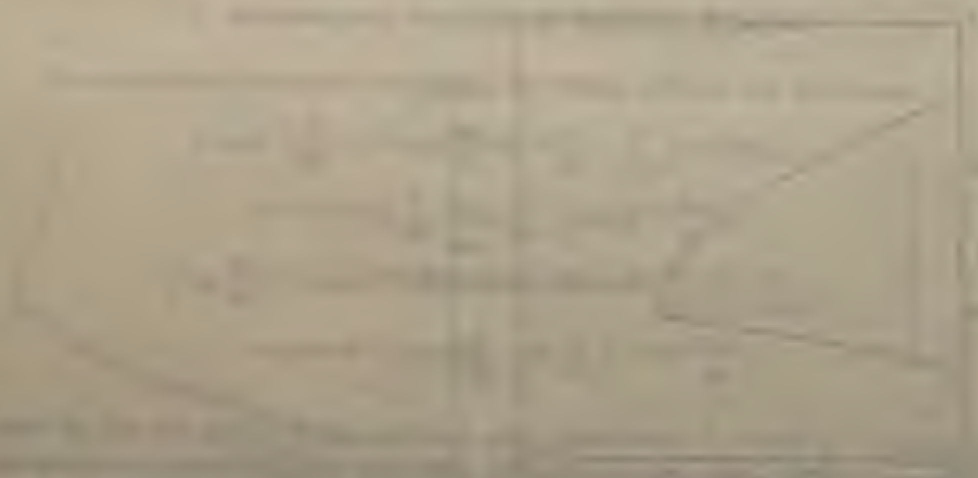


Fig. 1. Variation of Alfvén wave velocity against height. (a) was given by A.J. Dessler, and (b) was estimated from the height-distribution of the ionized gases conjectured from a Russian artificial satelite. In (b), the plasma density above the height, 3100 kms, is assumed to be constant, 100 protons/cm³.



surface is taken 0.3 gauss. It should be noticed that the Alfvén velocity varies in the ratio 100 : 1 within the height range of two or three thousands kilometers from the earth's surface. As the first approximation, we assume, therefore, that the Alfvén velocity does not depend on the polar angle θ. On this assumption, the above differential equation is solved by the method of seperation of variables:

$$E_\phi = \frac{1}{R} F(R) P_n^1(\mu), \quad n \geqq 1 \tag{4}$$

where n in one of integers not smaller than 1 and the function $F(R)$ is governed by the differential equation:

$$\frac{d^2F}{dR^2} + \left(\frac{a^2\omega^2}{V^2} - \frac{n(n+1)}{R^2} \right) F = 0, \tag{5}$$

where $n(n+1)$ is a constant of seperation.

This equation is the same type as that of propagation of a plane electro-magnetic wave in a non homogeneous and dispersive medium, of which dielctric constant ε is given by

$$\varepsilon = c^2 \left(\frac{a^2}{V^2} - \frac{n(n+1)}{\omega^2} \frac{1}{R^2} \right) \tag{6}$$

in the Gaussian units. On that case, the phase velocity is given by

$$v = \frac{c}{\sqrt{\varepsilon}} = \left(\frac{a^2}{V^2} - \frac{n(n+1)}{\omega^2} \frac{1}{R^2} \right)^{-1/2}, \tag{7}$$

and the group velocity V_g by

$$V_g = \frac{V^2}{a^2} \frac{1}{v} = \frac{V^2}{a^2} \frac{\sqrt{\varepsilon}}{c}. \tag{8}$$

Remembering that the region where the phase velocity is negative forms a barrier to reflect back the incident wave energy, we notice that the lower exosphere will be a barrier for hydromagnetic waves, the period of which is longer than $\sim$1 sec. Therefore, hydromagnetic waves excited in the lower part of the exosphere, presumably by impacts of auroral particles, will be propagated upwards as if a spherical wave and be reflected back somewhere in the lower exosphere. Thus, there would arise resonant oscillations.

It is an eigenvalue problem of the differential equation (3) to obtain periods of the geomagnetic pulsation. One of the boundary conditions may be that the field quantities will vanish at infinity. The other condition is, however, rather difficult. Alfvén waves propagated downwards will be attenuated in the ionosphere for existence of neutral particles (Dungey, 1954 a). The lower ionosphere, E and D regions, behaves as a metal-like substance for oscillatory electro-magnetic fields, of which period is of the order of the geomagnetic pulsation. Alfvén waves are, therefore, transformed into electro-magnetic waves in the lower sonosphere, and be attenuated due to Joules heat loss. That is, the lower ionosphere has a screening effect, which is more (less) effective, when the period is shorter (longer) and the electric conductivity is better (worse)

(Watanabe, 1957). When the period is of the order of 2 minutes, the screening will be negligible, and waves will be reflected back almost completely at the erath's surface because of its conductivity. In this case, the boundary condition is that the electric field will vanish at the lower boundary. When the period is of the order of 20 sec, the screening effect will be not always negligible. In that case, the condition at the lower boundary will be complicated. In every case, the evaluation of eigenperiods is very labourious without help of an advanced calculus machine.

A rough estimation of eigenperiod is, however, given as the time in which the Alfvén wave will make a return trip between the barrier and the earth's surface: 1 to 100 sec. The eigenperiod may be longer than estimated in such a way, due to ratardation near the reflexion point. Therefore, it may be possible that the hydromagnetic oscillation in the lower exosphere, is the origin of the geomagnetic pulsation.

It may be noticed, however, that not only the hydromagnetic occillation in the lower exosphere would be able to be the origin of the geomagnetic pulsation, but also the oscillation of all the matter within the exosphere be the origin as suggested by Dungey (1954 b). That is, there may be two kinds of geomagnetic pulsations corresponding to two different regions of the origin. Porf. Kato* and Mr. Yanagihara** gave a suggestion that the oscillation in the lower exosphere would give rise to pulsation, the period of which is of the order of several seconds which is named ' geomagnetic vibration ' by some authors. Mr. Yanagihara*** gave another suggestion that the oscillation in the lower exosphere would give the pc type pusation and the pt type pulsation would correspond to the oscillation in the region between the outer boundary of the cavity and the peak-point where the Alfvén velocity becomes maximum. Another suggestion would be possible as regards the difference between the periods of the two types of pulsations. Incidence of charged corpuscles at a higher latitude would give rise to an oscillation, one of which loops is situated at a higher latitude, that is, give rise to an oscillation of a greater n, which corresponds to an oscillation of a shorter period. These theoretical predictions should be checked by the studies in the future from both theoretical and observational sides.

3. Corpuscular Streams Responsible for Geomagnetic Pulsations

Occurrence of the maximum activity of geomagnetic pulsations, the periods of which are shorter than 45 sec delays one day compared with those of pulsations whose periods are longer than 90 sec and of the magnetic index A_k (Angenheister, 1945). It suggests that the velocity of the corpuscular stream responsible for the pc type pulsation is slower than that responsible for the pt type pulsation. Besides, we shall be led to a speculation that the velocity of the former stream may be that of the mean velocity of the solar corpular steam, presumably of the order of 10^8 cm/sec and that the velocity of the latter stream may be sufficiently high to precipitate the usal auroral zone, viz.,

*,** At this symposium, April 3, 1959.

*** Report at the meeting of Ionosphere Research Committee, held in Tôkyô, March 20, 1959.

near the reflection point [illegible]

lation in the lower exosphere [illegible]

It may be noticed [illegible] that not only [illegible] excitation [illegible]

[illegible] exosphere [illegible] in the [illegible]

the [illegible] of [illegible] the [illegible]

Dungey [illegible]. That is, there may be two kinds of geomagnetic [illegible]

corresponding to two different [illegible] the origin. Lord [illegible] and Mr. [illegible]

gave a suggestion that the [illegible] in the lower exosphere would give rise to pulsation,

the period of which is of the order of several seconds which is named 'geomagnetic

lation in the lower exosphere would give the pc type excitation and the pt type pulsation

would correspond to the oscillation in the region between the outer boundary of the

cavity and the peak point where the Alfvén velocity becomes maximum. Another

suggestion would be possible as regards the difference between the periods of the two

$\sim 10^9$ cm/sec. A close relationship between the pt type pulsation and the polar disturbance suggests that corpuscles responsible for both phenomena may be the same ones which impinge on the usual auroral zone. The fact that the pc type pulsation lasts continuously may be due to the circumstance that the corpuscular stream responsible for it would be a continuous one of corpuscles of the mean velocity. The other fact that the pt type pulsation occurs intermittently suggests that tne corpuscles responsible would be accelerated to the velocity $\sim 10^9$ cm/sec and would fly into the usual auroral region. It may be thought that magnetic clouds contained in the mean flow of solar corpuscles would accelerate some corpuscles to that velocity in the direction of the mean flow by the Fermi mechanism.

4. Concluding Remarks

It may be heuristic to estimate the eigenvalue of the differential equation (3) exactly, though any good agreement with observations is not to be expected bacause of the axi-symmetric assumption. We can obtain the eigenperiod with the help of advanced calculus machines, for example, differential analysers or electronic computers. A similar problem was treated very beautifully by Weekes and Wilkes (1947) in their studies on the tidal oscillation of the earth's upper atmosphere, which seem to be exemplary to theoretical studies in some respects.

To solve the fundamental equations (1) without the assumption of the axisymmetry but with an appropriate consideration on the lower boundary is, of course, a difficult but promissing problem in the future. It may be necessary to search relevant eigenoscillations in comparison to analysis of observational data on the geomagnetic pulsation.

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Discussion

Rikitake T.: Your estimation of the eigenperiod may be justified. It will not be very long, even if the retardation be taken into account.

Watanabe T.: It may be so. But, I wish to reserve my conclusive answer, till I shall try to estimate the eigenperiods more precisely.

Matsuura N.: I think that neutral particles in the lower ionosphere will partake the motion, and thus, the Alfvén velocity there will be slowed down severely.

Watanabe T.: Neutral particles are not moved directly by electromagnetic fields. They are moved indirectly through collisions with charged corpuscles, which moved directly by electromagnetic fields. However, motions of neutral particles are not coupled with the impressed external magnetic field, and thus, the kinetic energy will not be converted to an electromagnetic one. Therefore, neutral particles do not partake the propagation of Alfvén waves waves, but are effective for damping. If the number density is so great compared with that of charged corpuscles that the kinetic energy of charged corpuscles will be converted not to the electromagnetic energy but to the thermal energy of neutral particles through collisions, the conpling between motions of charged corpuscles and electromagnetic fields will be loosend. In this ase, Alfvén waves will no longer arise, but the electromagnetic energy will be propagated as damped electromagnetic waves, as in the case of electromagnetic waves in a metal.

10. Geomagnetic Pulsation Accompanying with the intense Solar Flare

By Yoshio KATO, Tsutomu TAMAO and Takao SAITO

Geophysical Institute, Faculty of Science, Tôhoku University

1. Introduction

Very intense solar flares were observed during the International Geophysical Year, and very remarkable micropulsations were also recorded by the induction magnetometer at the Onagawa Magnetic Observatory.

Usually we cannot detect the micropulsation caused by the solar flare in the record of the induction magnetograph, but at the time of these very intense solar flares, experienced during IGY, we observed very remarkable geomagnetic pulsations, continued in a few minutes and their periods were 70~100 sec.

There is a possibility that some kind of hydromagnetic oscillation in the earth's outer atmosphere will be excited by a sudden increase of the solar radiation accompanying with the intense solar flare.

2. Observed Micropulsation Accompanying with the Intense Solar Flare

Very intense solar flares were experienced during IGY. Following results were observed at the Tokyo Astronomical Observatory.

Date	Occurrence time (U.T.)	Intensity	Position in the sun's disk
1957 Sept. 19th	$04^h\ 00^m \sim 05^h\ 45^m$	III	5° E, 25° N
1958 July 29th	$03^h\ 03^m \sim 03^h\ 59^m$	III	44° W, 12° S
1958 Aug. 9th	no observation in Tokyo		
1958 Aug. 16th	$04^h\ 32^m \sim 06^h\ 10^m$	III_+	53° W, 15° S

On the other hand, very remarkable s. f. e. of geomagnetic field and also geomagnetic pulsations were observed accompanying with these solar flares.

Date	Occurrence time (U.T.)	Maximum Intensity (Pulsation, EW -component)	Period
1957 Sept. 19th	$04^h\ 03^m$	0.2 γ/sec	——
1958 July 29th	$03^h\ 02^m$	0.3 γ/sec	about 80 sec
1958 Aug. 9th	$03^h\ 48^m$	0.1 γ/sec	about 80 sec
1958 Aug. 16th	$04^h\ 34^m$	0.4 γ/sec	about 80 sec

Figs. 1~4 are recopies of these records. A is shown in the figures, the remarkable geomagnetic pulsations occurred simultaneously at Onagawa and Memambetsu, and the pulsations especially predominate in the EW component or Y compoint.

We have recorded these four examples, while we could not detect a geomagnetic pulsation at the time of the other solar flares observed during IGY.

3. A Possibility of Excitation of Hydromagnetic Oscillation in the Exosphere

The theories of s. f. e. of the geomagnetic field were presented by many authors and the s. f. e. of the geomagnetic field is explained by a sudden increase of S_q current due to the sudden increase of conductivity in the ionosphere.

However, the cause of the above-observed geomagnetic pulsation is yet obscure. It is the authors' opinion that the hydromagnetic oscillation may be excited in the outer atmosphere by a sudden increase of the solar radiation.

If the intensity of external radiation, illuminating a highly conducting gas which

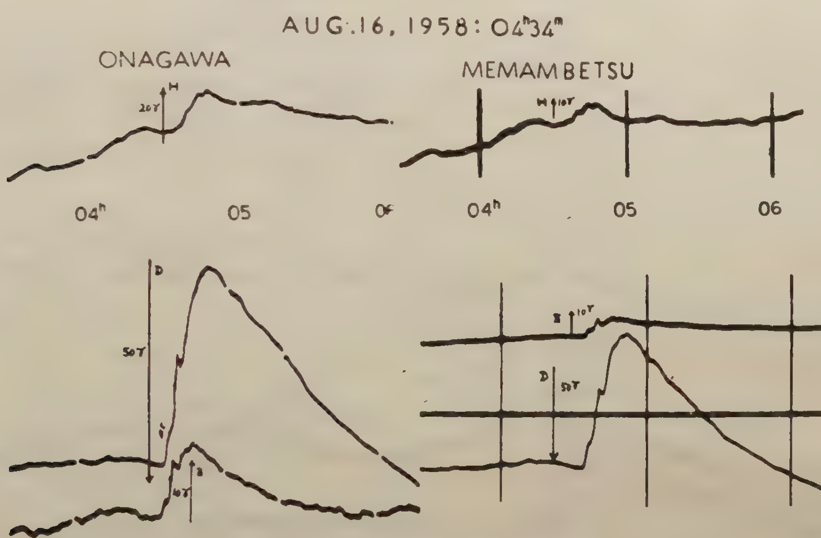

Fig. 1 A. Ordinary magnetogram.

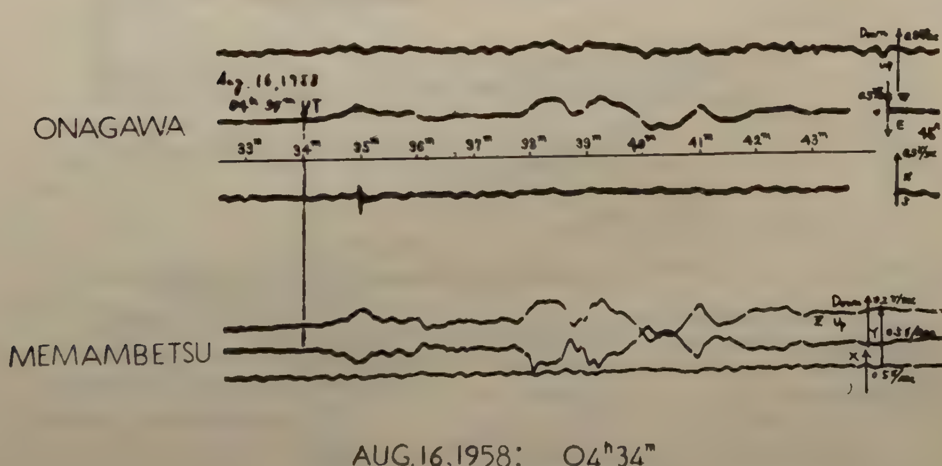

Fig. 1 B. Induction magnetogram.

rotates rigidly with magnetic field, increases suddenly and the radiative equilibrium condition is established within a rotating gas during a very short time, then the torsional oscillation of line of force will be excited through the magnetic restoring force.

We take here a very simple model that the spherical symmetric radiation increases its intensity suddenly, then

$$\begin{cases} \dfrac{\partial \boldsymbol{h}}{\partial t}=rot(\boldsymbol{v}\times\boldsymbol{H}_0)\,, \\ \rho\dfrac{\partial \boldsymbol{v}}{\partial t}=(4\pi)^{-1}rot\boldsymbol{h}\times\boldsymbol{H}_0-div\boldsymbol{P}\,, \\ div\boldsymbol{P}=grad\,p+\dfrac{1}{5c^2}grad\,(\boldsymbol{VF})-\dfrac{3}{5c^2}[\boldsymbol{V}\times rot\boldsymbol{F}-\boldsymbol{F}\times rot\boldsymbol{V}-\boldsymbol{V}div\boldsymbol{F}]\,, \end{cases}$$

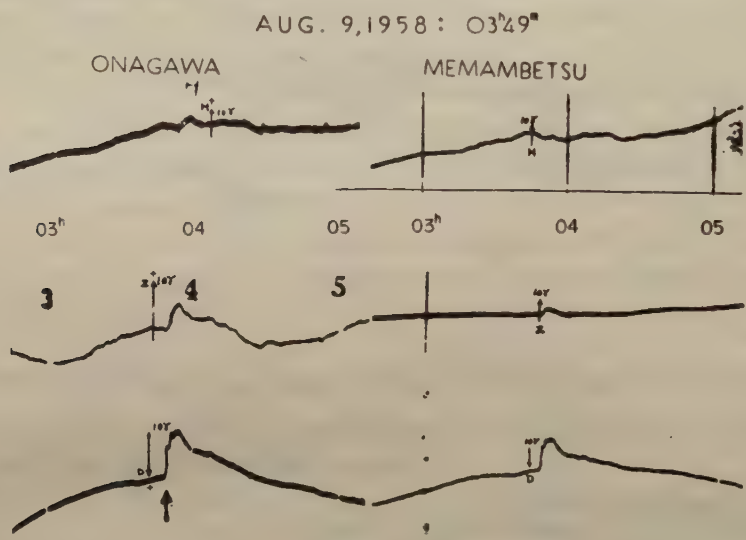

Fig. 2 A. Ordinary magnetogram.

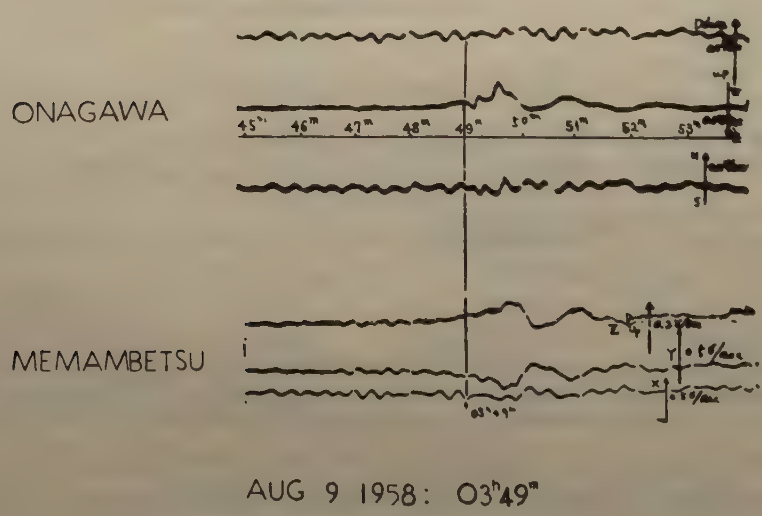

Fig. 2 B. Induction magnetogram.

where

h: perturbed magnetic field,

H: permanent magnetic field,

v: perturbed velocity,

V: rotational velocity,

p: gas pressure plus radiation pressure,

P: pressure stress tensor.

For the simplest case, we consider the axisymmetric case, then we have the following equation for perturbation field

$$\frac{\partial^2 h_\varphi}{\partial t^2}=\frac{\tilde{\omega}}{4\pi\rho}\boldsymbol{H}_0\,grad\left[\frac{\boldsymbol{H}_0 grad(\omega h_\varphi)}{\tilde{\omega}^2}\right]+\frac{\tilde{\omega}}{\rho}\boldsymbol{H}_0\,grad\left[2\Omega\frac{F_r}{r}+\frac{\Omega}{r^2}\frac{\partial}{\partial r}(r^2F_r)\right],$$

where

$\tilde{\omega}$: distance from the axis of rotation,

ρ: the density of conducting gas,

Ω: the angular velocity of rigid rotation,

F_r: incresed intensity of radiation.

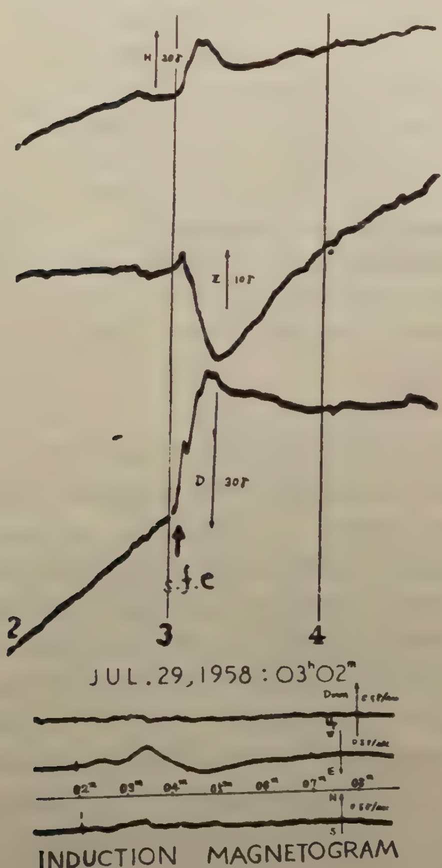

Fig. 3.

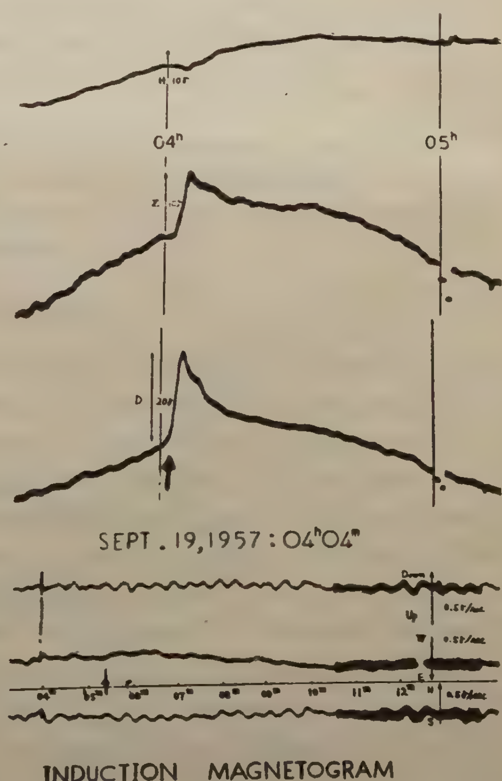

Fig. 4.

It is impossible to obtain the analytical solution of the equation, but under some approximation we can estimate the eigen period of the oscillation and the period in a few seconds in middle latitude. (Tamao T. Science Reports of the Tohoku University, Series 5, Geophysics Vol. 10, No. 3).

The periods of the above observed pulsation is rather longer with compared to that of toroidal oscillations for the axisymmetric model. While the condition of an increase of radiation is not spherical symmetry, therefore the coupling mode between the toroidal and poloidal oscillations will be excited. There is left an another possibility that the fluctuation of the ionospheric conductivity (corresponding to the fluctuation of the solar radiation) may excite the observed pulsations.

4. Conclusion

We showed the observed records of geomagnetic pulsation accompanying with the intense solar flare and suggested the possibility of the excitation of hydromagnetic oscillation in the outer atmosphere due to a sudden increase of solar radiation.

In conclusion the authors thank the Ministry of Education for its financial support.

11. On the Frequency of Geomagnetic Pulsation pc

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Abstract

Using a preliminary three-month table of IAGA, the hourly frequency of pc, F, which is first expressed by the number of pc appeared in each one hour interval in local time, is calculated at each of the fourteen observatories in Europe-Africa and Japan-Australia longitudinal zones, for each month and each season during the period from October, 1957 to June, 1958. It is found that for each season the mean maximum hour interval of the frequency falls around 9-11 hr in local time for the most observatories. And secondarily the ratio $F_m/\bar{F}$ is introduced, and it shows a remarkable dependency on the geomagnetic latitude, though the most important regions both equatorial and auroral zones can not be introduced, where F_m is the maximum value of F and $\bar{F}$ the mean value of F for each season.

It is also clarified by superposed-epoch method that the principal maximum peaks of daily numbers of observatories listed in the table appear one or two days after those of $\sum K_p$ during the whole period. The inverse relation is also checked.

It is suggested from these results that the outer atmosphere may become most sensitive in more extended depth than usual to the impinging solar agency over the earth within one or two days after the geomagnetic disturbances, probably in the higher geomagnetic latitudes.

1. Introduction

Following the resolution of the General Meeting of IAGA at Toront, 1957, various rapid changes in the geomagnetic field observed at many observatories in the world have been reported since October, 1957, in the specified form, to the Bureau of the IAGA Committee 10 on "Rapid Changes and Earth-Currents" at Ebro, Spain. These individual data are compiled in a three-month table, designated here as check-list, as preliminary world-wide data, and sent back to each corporating observatory. Since the essential part of character of rapid changes, especially of pulsations, of the distribution in space as well as in time has been yet remained obscurely because of scanty data of the world-wide corporating observation, the check-list wll play an important role in observations and in studying the rapid changes.

Recently, it has become very important to reexamine the characteristics of pulsations in aeronomical point of view by using the world-wide data of IGY, although various observational results have been accumlated at different part of the world and in

different epoch of the solar activity, which Kato and Watanabe made an extensive survey. So in this paper the frequency of pc is statistically investigated by using the IAGA table in respect to the dependency on local time, geomagnetic latitude and geomagnetic activity, since the check-list contains only time of beginning and ending of pc obtained from rapid-run recording. It is needless to define here what pc phenomena is meant by, because IAGA adopted the following category," Pulsations having a considerable element of continuity, having periods between 10 and 40 seconds, lasting a number of hours".

2. Hourly Frequency of pc

The time of beginning and ending of pc is tabulated in UT in the check-list, adjusting all available data, not extingushing recordings due to different method, say, by the rapid-run magnetometer and induction magnetometer for time changes of the intensity, and also ignoring the class of distinctness of appearance of pulsations. As annual summaries are issued, part of the data listed will be corrected.

Up to June, 1958, names of twenty six observatories are in the list, the following fourteen of them being continued from the very month of corporation, October, 1957. The present investigation is confined to the data of these observatories. As the table shows, in this paper are examined pc for

Table 1. List of Observatories Recording pc, Used in This Paper

Observatory	Abbr.	Geograph.			
		Lat.		Long.	
Lerwick	Le	60°	08′	358°	49′
Eskdalemuir	Es	55	19	356	48
Valentia	Ve	51	56	349	45
Hartland	Ha	51	00	355	30
Witteveen	Wi	52	49	6	40
Manhay	Ma	50	18	5	41
Toledo	Tl	39	50	355	57
Memambetsu	Mb	43	55	144	12
Kakioka	Ka	36	14	140	11
Tamanrasset	Ta	22	48	5	31
Quetta	Qu	30	11	66	57
Apia	Ap	−13	48	188	14
Hermanus	Hr	−34	26	19	14
Watheroo	Wa	−30	19	115	53

two principal zones, Europe-Africa and Japan-Australia longitudinal zones, of IGY program.

In order to see how many pc's and how long their duration are observed at each observatory, total numbers of pc's,F, contained in each one hour interval of local time are first counted for each month and each season, ignoring whether or not the interval is wholly occupied by the waves. Each hourly frequency curve thus obtained is predominant with a single maximum in day time, though a second earlier maximum,

with comparable magnitude to the principal maximum, is observed at Le and Ap in Equinox, and at Tl in Winter, respectively. As shown in Fig. 1, the maximum of F shows no dependency on UT and geomagnetic latitude, but appears around the interval 9-11 hr in local time at most observatories even as for different seasons, except earlier occurrences in Summer and in Winter at Ta, and in Winter at Wi; where three seasons are meant as follows; Summer (May and June, 1958), Equinox (October, 1957; March and April, 1958) and Winter (November and December, 1957; January and February, 1958).

The maximum values of the elements of F are given in Table 2. As it is seen from the table the maximum number of F at Mb, Ka and Hr are larger twice or more those of the other observatories. We have no published detailed information of the scaling method at each observatory, although the definition of pc and corresponding "Provisional Atlas" are given by the IAGA Committee 10. It is likely that so many complicated cases may be encountered at observatories as even skilful observers may be pending for some time to decide the lower limit of selection. The table shows that one can not take Fm's themselves as a unified quantity suitable for comparison of the frequency of pc. However, if the ratio $Rm=Fm/\bar{F}$ is introduced, the world-wide distribution of the hourly frequency of F may be deduced, provided that the constant scaling standard is maintained at each observatory througout the period considered, where $\bar{F}$ is the mean value of F for each season. The result is shown in Fig. 2, in which nearly symmetrical dependency of Rm on the geomagnetic latitude is clearly seen for each season. However, in order to complete the graph it is very desirable to add some points in both equatorial and auroral or higher latitudes in the both hemispheres.

It is well known that the pulsation pc is originated in the outer atmosphere, extending far beyond the ionosphere, by the Alfvèn hydromagnetic waves. If the

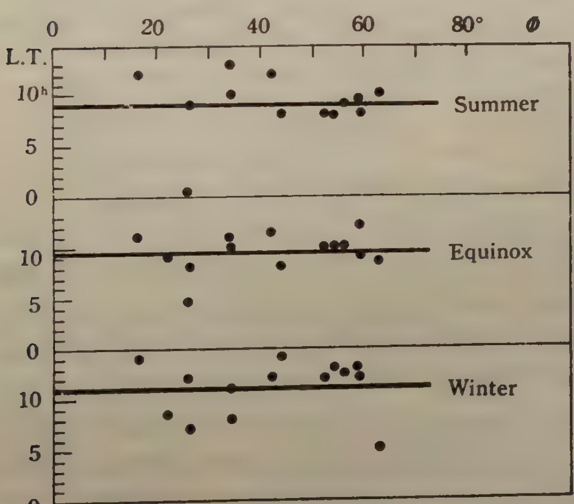


Fig. 1. Maximum hour interval of the frequency of pc, and geomagnetic latitude.

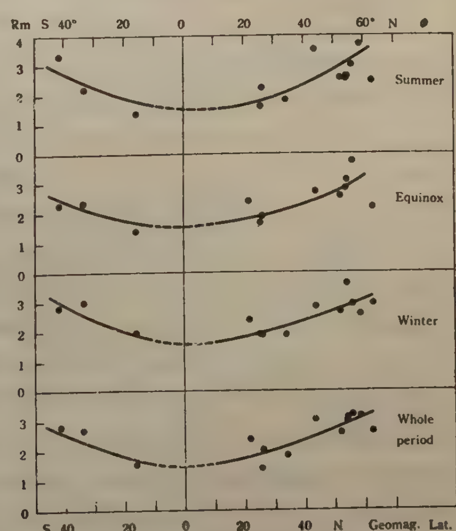


Fig. 2. $Rm=Fm/\bar{F}$ and geomagnetic latitude.

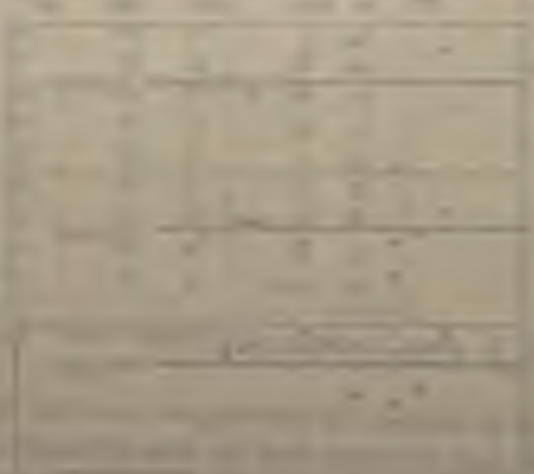
[illegible]

one can not take [illegible] as a [illegible] quantity [illegible]

[illegible] $F-\bar{F}$ [illegible]

distribution of the [illegible] of F may be deduced, provided that the [illegible] standard is maintained at each observatory throughout the [illegible] considered, where $\bar{F}$ is the mean value of F for each season. The result is shown in Fig. 2, in

[illegible]



impinging solar particles into the earth disturbe more frequently the upper atmosphere as Störmer's orbits over the higher geomagnetic latitude, such as auroral zone, than over the lower latitude, the observed increasing Rm with increasing geomagnetic latitude can be expected.

In the above statement the frequency of pc is treated in terms of F. However, the frequency of the time of occurrence of pc is related experimentally to that of F as following. If t_o is denoted by the hour interval of the maximum frequency of time of occurrence of pc, and t_d by the mean value of duration hours of pc, the following relation among the fourteen observatories approximately hold for each searon,

$$t_o + at_d = c\,,$$

where a and c are some constants. The value of c is approximately equal to the mean tm in Table 2 of the fourteen observatories. An example for Equinox is shown in Table 3.

Table 2. Maximum values of the elements of F

Obser-vatory	Summer			Equinox			Winter			Remarks
	Fm	tm	Rm	Fm	tm	Rm	Fm	tm	Rm	
Tl	27	8	3.54	27	7	2.74	28	14	2.87	Fm: Maximum number of F
Es	7	9.5	3.72	4	12	6.90**	11	13	2.62	tm: Hour interval in which
Le	26	10	2.46	27	8.5	2.19	26	5	2.97	maximum of F appears;
Ha	24	8	2.54	24	10	2.82	10	13	3.67	tm=7 means the hour
Ta	16	0.5	1.60	25	4.5	1.70	25	12	1.96	interval $7^h \sim 8^h$ in local
Ma	37	7.5	2.58	24	10	2.57	19	12	2.69	time.
Wi	17	8	2.62	19	9	3.12	18	12	3.66	*: Values in Summer are
Vl	17	10	3.02	16	9	3.76	11	13.5	2.94	plotted in Winter graph
Hr*	14	11	3.61	34	11	2.34	63	13	2.18	in Fig. 1 and Fig. 2.
Qu	—	—	—	13	9	2.40	11	8.5	2.39	**: Omitted, for very few
Wa*	14	12	2.80	26	11.5	2.29	22	12	3.33	numbers of F.
Ka	42	9	2.26	48	8	1.90	53	7	1.92	
Mb	50	10	1.84	59	10	1.79	92	8	1.92	
Ap*	25	14	1.98	50	11	1.41	25	12	1.36	

Table 3. Frequency of time of begining of pc and its duration (Equinox)

Obser-vatory	Tl	Es	Le	Ha	Ta	Ma	Wi	Vl	Hr	Qu	Wa	Ka	Mb	Ap	Mean
t_o*	6	12	7.5	7	4	9	7	7	8	5	5	3	4	4	6.3
t_d*	3.4	2.1	4.6	5.9	5.7	4.4	4.5	2.7	7.8	6.3	8.9	8.3	9.7	11.0	6.1
$t_o+0.78t_d$	8.6	13.6	11.3	11.6	8.4	12.4	10.5	9.1	14.0	9.9	11.9	9.5	11.6	12.6	11.1
tm*	7	12	8.5	10	4.5	10	9	9	11	9	11.5	8	10	11	9.3

* Mean value is shown when two equal values are observed.

3. Daily Frequency of pc and Geomagnetic Activity

In the preceding section it is shown that the frequency of pc is remarkably

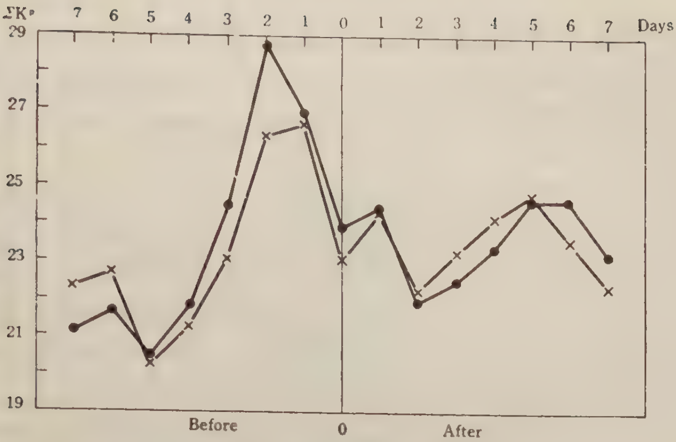


Fig. 3. Frequency of pc and geomagnetic activity.
Black circle: N≥10 cross: N≥5

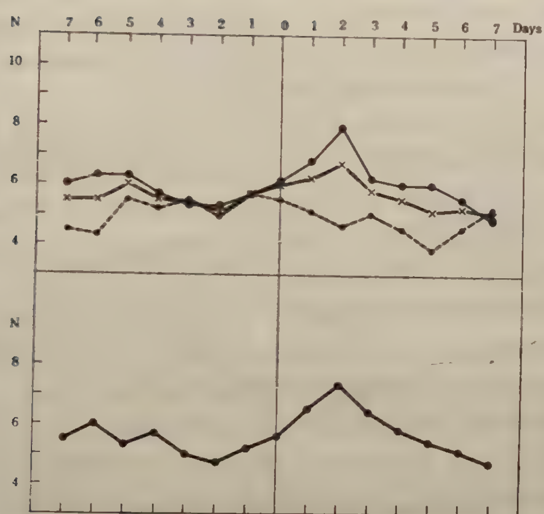


Fig. 4. Upper curves:
●———● $\sum Kp \leq 30$ (A)
●··········● $30 > \sum Kp \geq 20$ (B)
×———× (A)+(B).
Lower curve: Magnetic storms.

controlled by the geomagnetic latitude of the observatory, though important points in the equatorial and auroral zones are not introduced. Then it is natural to expect some connection betwee the frequency and geomagnetic activity. Now, counting the daily total number of observatories listed in the check-list among the fourteen ones said above, and is designated by N, let, as a measure of the geomagnetic activity, take the daily sum of Kp, ΣKp, and plot N and ΣKp on the same sheet. Then, it is first noticed that almost all principal maximum peaks of N appear as if they follow those of ΣKp within one or two days after. This circumstance can be clearly shown in Fig. 3 and 4, which are drawn by the Chree's superposed-epoch method. In Fig. 3 the zero-day for the curves shown by black circles expresses the days of the maximum peaks of $N \geq 10$, which amount to 32 days, while for another curve it corresponds to the case of $N \geq 5$ with the total number of 46 days. The maximum peak of N appears one or two days after that of ΣKp, and ΣKp increases with increasing N. This shows first that the results are consistent with the geomagnetic dependency of the frequency given in the preceding section, and secondarily suggests that the outer atmosphere becomes most sensitive in larger area and to lower depth than usual to the agency to raise up the shorter period pulsation within one or two days after the geomagnetic disturbances become the largest. Since ΣKp expresses well the geomagnetic activity in the higher

latitudes, the upper atmosphere may become more sensitive in the higher latitude than in the lower latitude. It may be imaged also that the agency responsible for pc, probably the solar corpuscular radiation, is intensified or comes in with lower velocity after larger geomagnetic disturbances.

Fig. 4 shows the inverse relation of N and ΣKp to that given in Fig. 3. The zero-day corresponds to the maximum peaks of ΣKp, and the values of N before and after them for seven days are superposed. The value of N increases with increasing ΣKp; for small ΣKp there is found no two-days retardation of N behind ΣKp. The lowest curve shows the relation corresponding to nineteen geomagnetic storms, mainly of SC type.

§ 4. Conclusion and Proposals

By the preliminary three-month table of IAGA of the data of world-wide rapid-run observations, during the period from October, 1957 to June, 1958, various characteristics of the frequency of geomagnetic pulsation pc were much clarified in respect to its dependency on local time, geomagnetic latitude and geomagnetic activity.

However, the table of IAGA contains no data from North nor South, America, the continents that make one of the three principal zones of IGY observions, and further, little contributions from the equatorial and higher latitudes were obtained. It is very desirable to extend the function of the Committee to collect all available data in these continents as well as in USSR.

The magnitude of frequencies and duration time of pc at some obseavatories amoung the selected fourteen stations are so different from other ones. It is therefore earnestly desired to standardize the method of scaling to decide the lower limit of selection in each observatory at the coming symposium on rapid changes and earth-currents at De Bilt.

At the same time any theoretical effort should be encouraged to discuss the phenomena of pulsations from the standpoint of a unified field theory of earth's storms.

12. Studies on the Local Character of the Geomagnetic Pulsaton, Pc

By Shinkich Utashiro

Hydrographic Office, Maritime Safety Agency.

Abstract

It is well known that Pc type pulsation occurs simultaneously in the world wide region. The author examined the records of induction magnetometer at the Japanese four stations (Memanbetsu, Onagawa, Simosato and Kanoya). Results are as follows.

1) The local Pc occurs frequently during daytime.

2) The maximum of occurrence frequency of local Pc lies in equinox, and the minimum lies in winter.

3) The frequency of occurrence of local Pc depends on local mean time, and the maximum frequency of it's occurrence lies around 13h (L. M. T.).

1. Introduction

Since 1946, routine observation for magnetic pulsations were done by induction magnetograph at the Onagawa Magnetic Observatory and many observational knowledge was given by Y. Kato and his colleagues (1951).

Since July 1957, the International Geophysical Year was held by the cooperation of many countries in the world. The observation of the pulsation by the induction magnetograph was continued at the four Japanese magnetic observatories. The time variation of three components, $\frac{dX}{dt}$, $\frac{dY}{dt}$ and $\frac{dZ}{dt}$, were recorded at Memanbetsu and Kanoya, and $\frac{dH}{dt}$, $\frac{dD}{dt}$ and $\frac{dZ}{dt}$ were recorded at Onagawa and Simosato by the induction magnetograph.

2. Local inequality of Pc

It has been considering that Pc type pulsation occurs simultaneously in the world region. The author examined the induction magnetograms during IGY at four stations in Japan.

By the results of the study, local inequality of Pc was found. Fig. 1 show typical examples of the records of local Pc. In these figures X show north components of magnetic field respectively. And K, S, O and M show Kanoya, Simosato, Onagawa and Memanbetsu respectively. As Fig. 1 shows, period or mode of north component of Pc obtained by induction magnetograph at the four stations are not quite same. The period or mode of north component of Pc change with latitude.

It is seemed that amplitude of north component of Pc becomes larger with increa-

are as follows.

2. The amount of magnetic ...

the minimum ...

The time ... of occurrence of ...

and the ... frequency ...

1. Introduction

Since 1949, routine observation for magnetic pulsations ...

magnetograph at the Onagawa ...

sing latitude. But about east-ward component such phenomenon is not seen. About the east-ward component of Pc, the very similar Pc type pulsations were observed at four stations. Therefore such local inequality of Pc occurs only about the north component of pulsations.

3. Frequency of occurrence of local Pc, daily variation and seasonal variation

During the period from January to September 1958, the many local inequality of Pc were observed at four stations. The author studied daily variations and seasonal variations of occurrence frequency of local Pc using these data, and found the following remarkable characters.

A. On the daily variation.

(1) The local Pc type pulsations occur most frequently during period from 10 h to 18 h (L. M. T.). The Pc type pulsations which occur during period from 19 h to 9 h show the same phase in four stations.

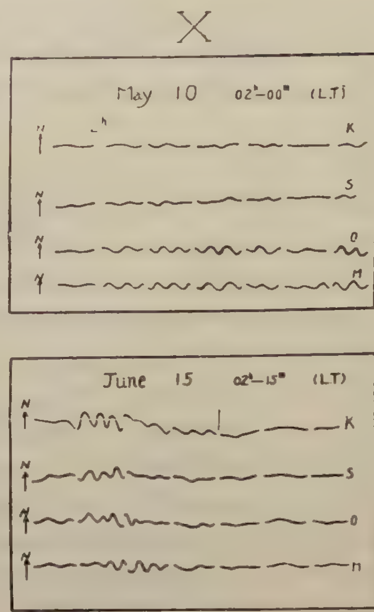


Fig. 1.

(2) The relative frequency of occurrence of local Pc is shown in Fig. 2. As the figure shows, the local inequality of Pc type pulsation occurs most frequently in afternoon. The maximum frequency of occurrence of local Pc lies round 13 h (L. M. T.).

B. On the seasonal variation.

(1) The annual frequency of occurrence of local Pc is shown in Fig. 2 and Fig. 3.

(2) As shown in figures, it seems that the maxima of occurrence frequency lie in the equinoxes, and such pulsations are less frequent in winter than the other seasons.

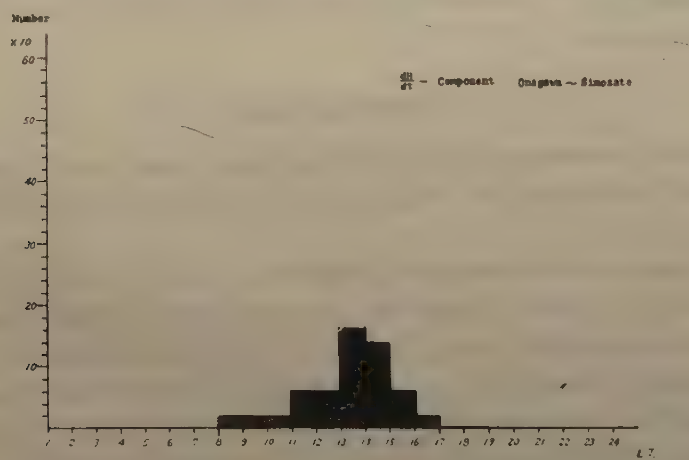
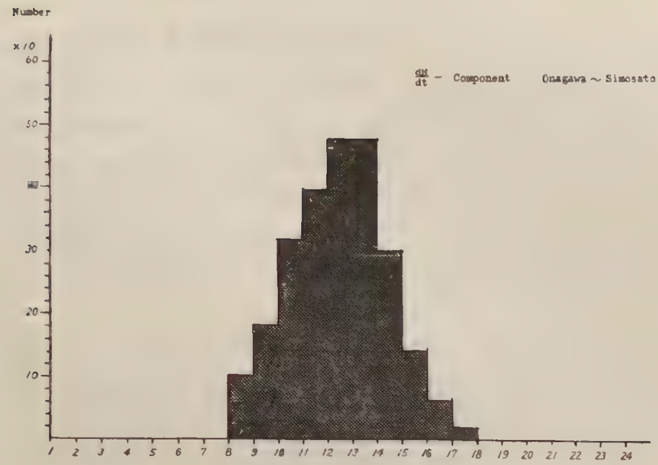
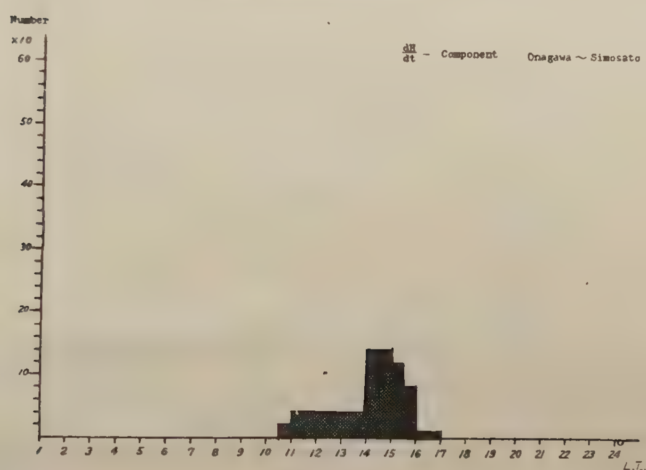


Fig. 2. (1) Frequency of occurrence of local Pc, daliy variation and seasonal variation.



September

Fig. 2. (2) Frequency of occurrence of local Pc, daily variation and seasonal variation.



November

Fig. 2. (3) Frequency of occurrence of local Pc, daily variation and seasonal variation.

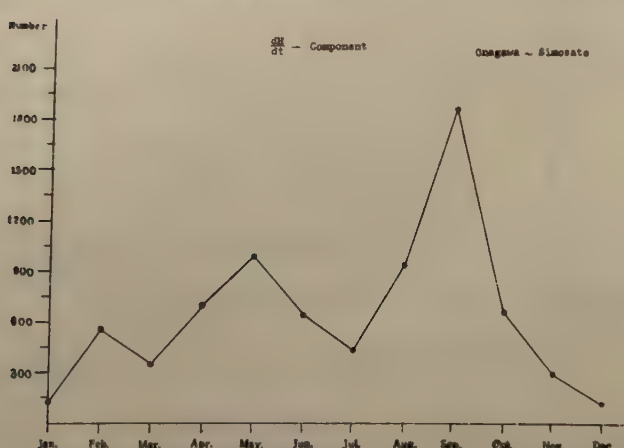
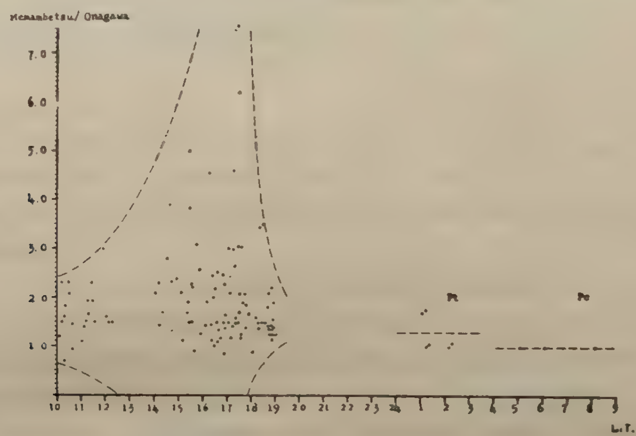


Fig. 3. Seasonal variation of frequency of occurrence of local Pc.

4. On latitude distribution of amplitude of Pc

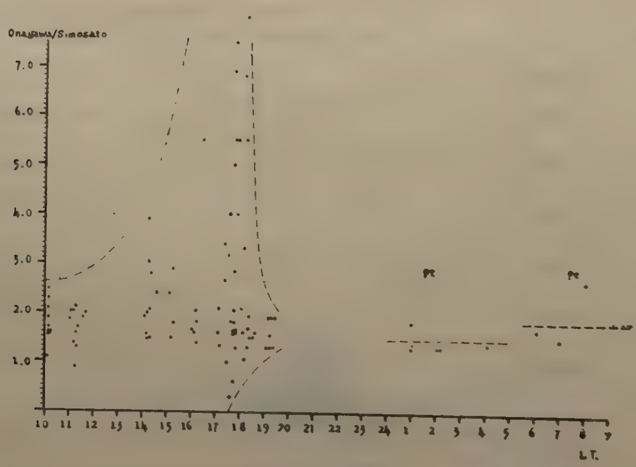
Using the data during the period from January to September 1958, the author studied on the latitude distribution and time variation of amplitude of Pc type pulsation. At first, the author compared the amplitude of Pc which occurs simultaneously in four stations. The time variation of the amplitude ratio of Pc observed at two stations is shown in Fig. 4. In Fig. 4, the ordinate show the amplitude ratio at two stations, Memanbetsu/Onagawa, Onagawa/Simosato, and Simoto/Kanoya. The component of Pc type is shown by geographic component.

As shown in Fig. 4, the local Pc type pulsations occur most frequently during period from 10 h 18 h (L. M. T.) on the north component of magnetic field. The Pc type pulsations which occur during period from 19 h to 9 h show the same phase in four station. The amplitude ratio of Pc shows a constant value during period from



June 15, 1958

Fig. 4. (1) Time Variation of Amplitude Ratio of dX/dt at Two observatories.



June 15, 1958

Fig. 4. (2) Time Variation of Amplitude Ratio of dX/dt at Two observatories.

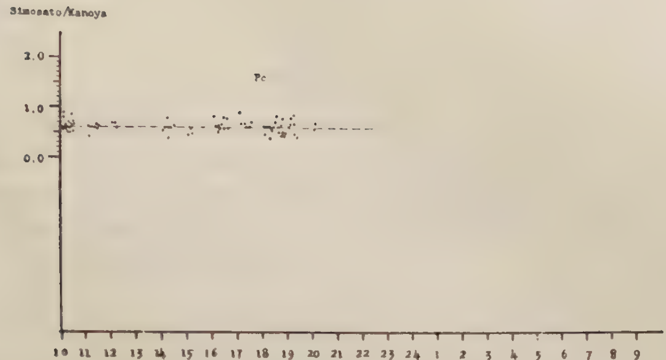


Fig. 4. (3) Time Variation of Amplitude Ratio of dX/dt at Two observatories.

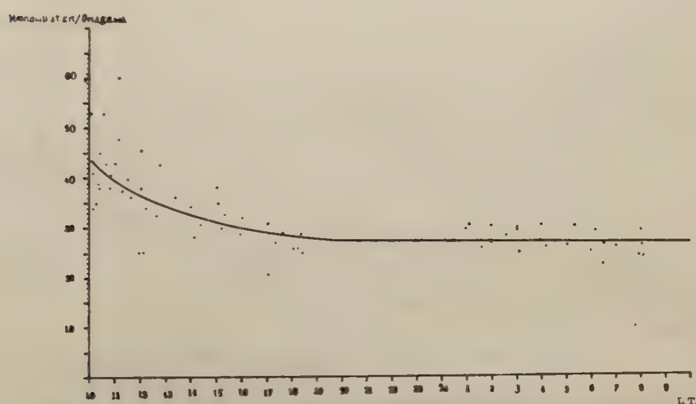


Fig. 4. (4) Time Variation of Amplitude Ratio of dY/dt at Two observatories.

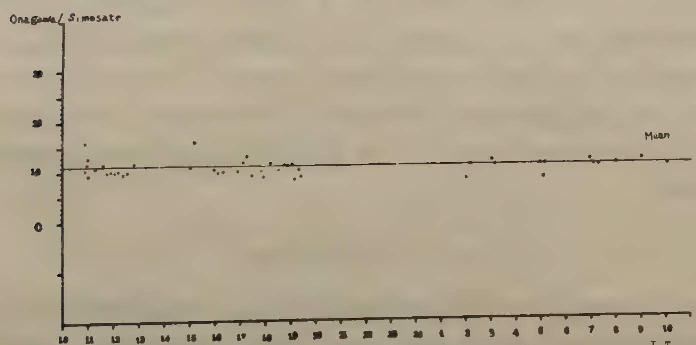


Fig. 4. (5) Time variation of Amplitude Ratio of dY/dt at Two observatories.

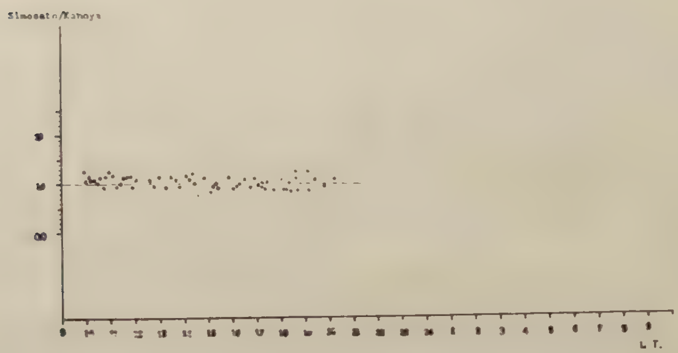


Fig. 4. Time variation of amplitude ratio of dY/dt at two observatories.

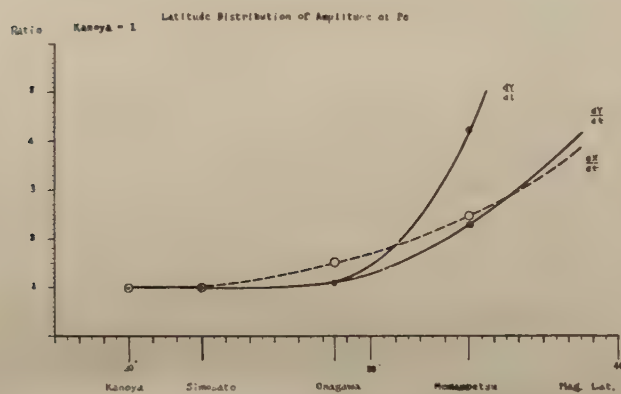


Fig. 5. Latitude distribution of amplitude of Pc.

19 h to 9 h (L. M. T.). The latitudinal distribution of the Pc type pulsation which occur during period from 19 h to 9 h (L. M. T.) is shown in Fig. 5. On the such Pc type pulsation, we can see a tendency that amplitude increases respectively with geomagnetic latitude. According to the above studies, it has become clear that there are two kinds of Pc type pulsation, one kind of Pc occurs simultaneously in the wide region and the phase and period of the pulsation is the same, other kind of Pc show local character.

5. Conclusion

It is very interesting that the local inequality of Pc was observed in Japan, and important to point out that such phenomena were observed at several stations where situated at about 20° (geomagnetic latitude). Such phenomena were frequently observed in the daytime hemisphere in middle latitude. According to the studies (Kato and Akasofu, 1956; Kato and Watanabe, 1957; Obayashi, 1958) on hydromagnetic oscillations of the outer atmosphere, it seems that Pc type pulsation caused by the hydromagnetic oscillation of the outer atmosphere excited by the corpuscular streams from sun. Therefore,

such local Pc type pulsation may be produced by the hydromagnetic scillation of the outer atmosphere.

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Discussion

Kato Y.: Can I recognize many local Pc in the daily induction magnetogram in the daytime?

Utashiro S.: Yes, the such local Pc type pulsations frequently occur in the daytime?

Yoshimatsu R.: You may get interesting results if you shall analyse the reports of IGY from the 10 th committee.

Utashiro S.: I will do so.

Ota M.: Do you think as to instruments for observation of the magnetic pulsation. You have better also study on many quick run magnetograms collected to the data centre of IGY.

Utashiro S.: I will study it in the future.

13. Preliminary Studies on the Daily Behaviour of Rapid Pulsation

By Yoshio KATO and Takao SAITO

Geophysical Institute, Faculty of Science, Tōhoku University

Abstract

The authors analysed the daily variations of the period of rapid pulsation: pc, pulsation accompanying with ssc or si, and a small short period pulsation on the stormtime. It is found that the shortest period of these pulsations is long in the daytime and becomes apparently short in the nighttime, and shows clearly daily variations.

1. Daily Variation of the Period of the Rapid Pulsation Accompanying ssc with or si

It is very interesting that a single train of rapid pulsation sometimes appears with the sudden commencement of the magnetic storm or the sudden impulse in the daytime, while it is very much weakened or unnoticeable during the nighttime. Actually these characters are observed clearly on the records of the induction magnetometer (Kato and Saito, 1958).

These rapid pulsations appear usually with a sudden commencement of the intense magnetic storm, and the period of these pulsations is about 20 sec in the daytime, while it becomes short in the nighttime, namely, a few seconds.

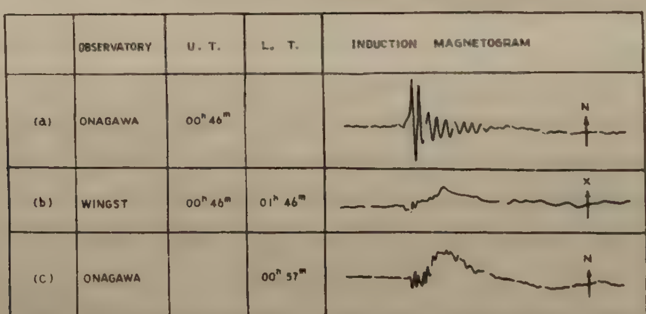


Fig. 1. Local time dependency of the pulsation accompanying with ssc.

Fig. 1 shows a model-like example of these rapid pulsations, that is, Fig. 1 (a) is a record of the daytime-type rapid pulsation observed by the induction magnetometer at the Onagawa magnetic observatory, which occurred simultaneously with ssc on 00^h46^m U. T. of June 25th, 1957 (09^h46^m L. M. T.) and clearly shows that the period of this pulsation is rather long. While Fig. 1 (b) is a record of the nighttime-type rapid pulsation observed by the induction magnetometer at the Wingst magnetic observatory, which occured simultaneously with the same ssc on 00^h46^m U. T. of June 25th, (01^h46^m L. M. T.) and

clearly shows the period is very short. Fig. 1 (c) shows the other rapid pulsation obtained at the Onagawa magnetic observatory in the nighttime and shows also that the period is very short.

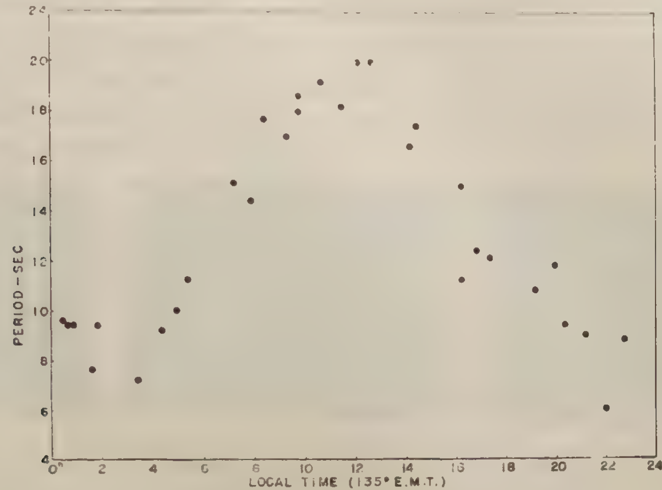


Fig. 2. Daily variation of the period of the pulsation accompanying with ssc or si.

Now we get Fig. 2 by counting the periods of the rapid pulsations accompanying with typical 26 ssc's and 5 si's which occured in the interval of 1957 and 1958. As is seen in this figure the periods of these pulsations show the character of fine daily variation.

2. Daily Variation of the Period of pc

It is well known that the quasi-stationary pulsation of the geomagnetic field, that is, pc type pulsation, occurs generally in the daytime only. Therefore it is too difficult to get the whole daily variation of the period of pc. But, sometimes pc occurs even in the nighttime when the magnetic disturbance is active, and we can read the period of

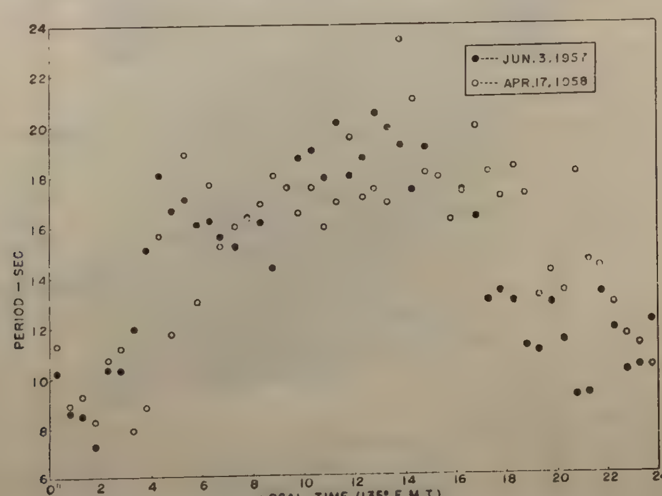
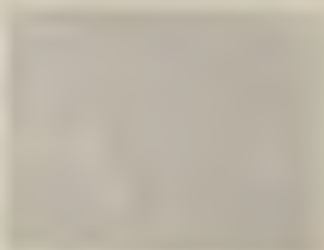


Fig. 3. Daily variation of the period of pc type pulsation.



pc on the induction magnetogram, thus we obtain of the period of pc throughout the whole day. Fig. 3 shows this daily variation of the period of pc and it is clear that the period of pc in the daytime is longer than that in the nighttime. This character is very similar to that shown in the section 1. We can directly record the changes of the vector diagram of these pulsations, pc, by using an induction vector magnetometer. An example is shown in Fig. 4 which shows that the azimuth of the principal axis of the perturbing vector of pc changes its direction at the time of sunrise or sunset.

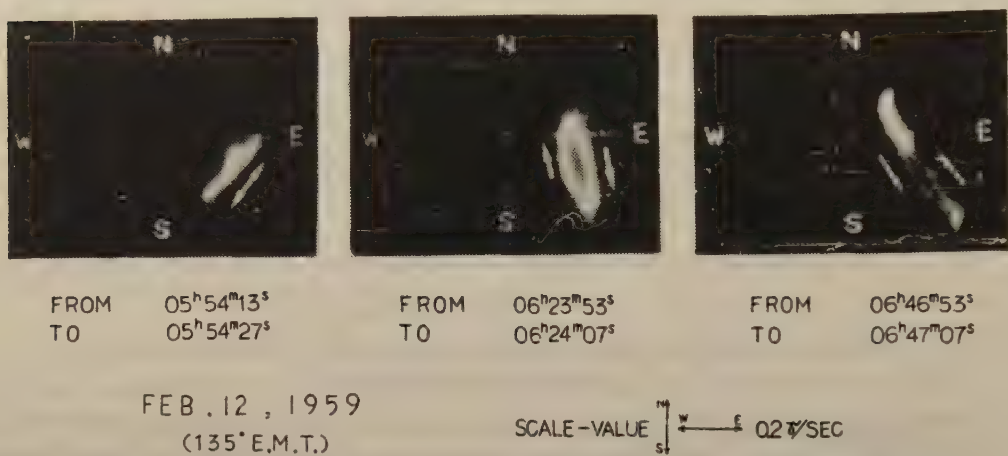


Fig. 4. Examples of the induction vector magnetogram near the time of sunrise.

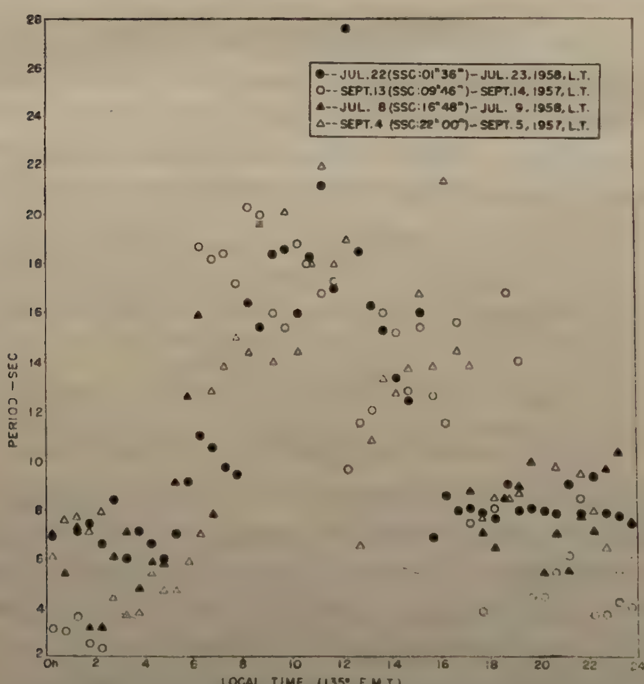


Fig. 5. Local time dependency of the shortest period of pulsation during magnetic storm.

3. Daily Variation of the Period of the Shortest Pulsation Occurred in Magnetic Storm

During magnetic storm, we observed very intense and irregular storm-time rapid pulsations. We examined the daily behaviour of these rapid pulsations, that is, we read the shortest period of the pulsation in the cases of storms, of which (sudden commencements) are about 2^h, 10^h, 17^h, and 22^h L. T. respectively. Then the periods are arranged on the same abscissa of the local time. Thus we get Fig. 5, which shows clearly that the periods of these pulsations show a similar daily variation, that is, the period is longer in the daytime than in the nighttime and it does not depend on the local time of ssc. Beside this behaviour, the period of the storm-time pulsation becomes short at intense stages of the disturbance, which is overlapped by the above stated daily change.

4. Daily Behaviour of the Rapid Pulsation

As above stated, we discussed the daily variation of the period of pc and other pulsations, and it becomes clear that the period of pc or the shortest period oscillation in the storm-time pulsation is longer in the daytime and becomes short in the nighttime. On the other hand it is well known that the occurence frequency of pt is maximum in the nighttime and the period from 40 sec to 100 sec is most frequently observed

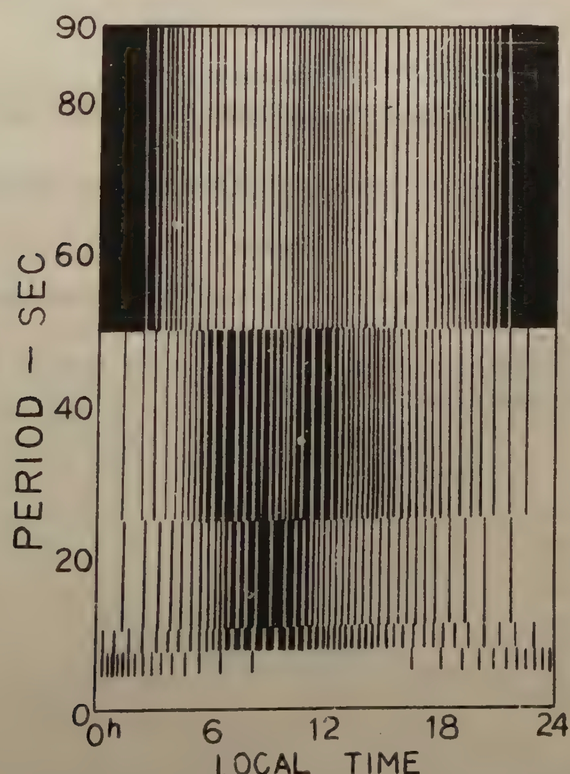


Fig. 6. Schematic daily behaviour of the rapid pulsation.

for pt. (Small rapid oscillations overlapped on this long period of pt are not included. It seems that such overlapped pulsation has the same behaviour as stated in the section 2, and these characters will be reported in the near future.) Therefore, we can describe Fig. 6 schematically in which we take the local time on the abscissa and the period of the pulsation on the ordinate and the amplitude of the pulsation is indicated by grade of blackness (Kato, Ossaka, Okuda, Watanabe and Tamao, 1956).

5. Discussion

As already discussed by many authors, it is well known that the rapid pulsation of geomagnetic field is caused by hydromagnetic oscillation in the outer atmosphere, though there remains obscurity of exciting mechanism for the hydromagnetic oscillation. We can expect the hydromagnetic oscillation of the outer atmosphere excited by turbulent motion of the corpuscular stream. The above stated observational fact that the period of oscillation becomes abruptly short at intense stages of the magnetic storm, suggests that the outer atmosphere would be suddenly contracted at each stage, while we can also expect a standing oscillation inside the Van Allen belt which is recently observed by the satellite (Van Allen, Wcllwain and Ludwig, 1959). At any rate, we must put in order all the results of the world-widely distributed observations, and then we must investigate the mechanism of geomagnetic rapid pulsation.

In conclusion, the authors should like to express their sincere thanks to Prof. J. Bartels for sending them his important microfilms of the magnetogram at the Wingst Observatory. The authors also thank the Ministry of Education for its financial support.

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Discussion

Yanagihara K.: I think the period does not vary gradually, but discontinuously towards daybreak and towads evening.

Saito T.: It ispossible to think so, but we only cleared that the period of pulsation is long in the daytime and short in the nighttime.

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